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WASTE MANAGEMENT

SOLID WASTE

Solid waste is any type of discarded material that is not in a liquid or gaseous state. It is produced by human activities, including household, business, and industrial ones. Solid waste can come in various forms, such as debris, garbage, sludge, refuse, and construction waste. It can include both biodegradable and non-biodegradable materials, such as food waste, plastics, glass, paper, metals, and electronic devices.

Sources of Solid Waste

Status of Solid Waste Generation in India

- According to the Central Pollution Control Board's (CPCB) report for 2021, the MSW generation rate in India was 160,038.9 tons per day (TPD), or approximately 0.119 kg per capita per day.
- Approximately 95.40% of the total waste was collected and transferred to disposal sites.
- However, 50% was processed and treated by all types of waste treatment facilities prior to disposal

Waste Category	Waste Category and Definition	Constituent Components
Residential/ Household	This type of waste is generated in residential areas due to human and household daily activities.	Food residues, paper, cardboard, plastic, textiles, glass, metals, wood, ashes, electronic items, batteries, oils, household hazardous wastes such as paints, solvents, cleaners, pesticides, etc.
Commercial/ Institutional	These are the wastes generated from large institutional and/or commercial activities such as marketplaces, retail stores, restaurants, hotels, hospitals, government and private offices and buildings, etc.	Food residues, paper, cardboard, plastic, rubber, textiles, glass, metals, wood, heavy items, batteries, oils, hazardous wastes, etc.
Municipal Service	These wastes are from sources like street cleaning, assemblies in parks, recreational activities, entertainment places, and relaxing places-beaches, etc.	Street cleaning, tree trimmings and dry leaves, general wastes from parks, beaches, and other recreational areas
Bio Medical	Waste generated during diagnosis, treatment, or immunization of human beings or animals or in research activities	Bandages, plaster casts, materials contaminated with blood, tubes, catheters, hypodermic needles, syringes, scalpels and broken glass, Human anatomical waste like tissues, organs and body parts etc.
Agricultural	Agricultural solid wastes are produced mainly from farming activities and activities associated with farming.	Animal production solid wastes, food and meat processing solid wastes, crop production solid wastes, On-farm medical solid wastes, Horticultural production solid was etc.

Impact of Solid Waste

On the Environment:

- **Contamination of Soil:** Improper disposal of solid waste can contaminate the soil with chemicals, heavy metals, and other pollutants. This reduces soil fertility, and hinders plant growth. Further, pollutants can leach into groundwater and contaminate it.
- **Habitat Destruction:** Disposal of waste in natural habitats or water bodies, can lead to habitat destruction. Animal including marine species suffer from entanglement, ingestion, and suffocation due to waste disposal.
- **Greenhouse Gas Emissions:** Organic waste in landfills undergoes anaerobic decomposition, and releases methane. Further, certain solid waste management processes such as incineration release greenhouse gases.

- **Wastage of Resources:** Improper waste management and lack of recycling leads to the wasteful consumption of resources, increasing the demand for virgin materials.

> **DO YOU KNOW?**
>
> According to the UNEP, by 2050, approximately 15 percent of the permissible greenhouse gas emissions will be attributed to the production, usage, and disposal of plastic.

On Human Health:

- **Water and Air Pollution:**
  - Waste material can seep into water bodies and contaminate them. Consumption of contaminated water can lead to various waterborne diseases such as cholera, dysentery, and hepatitis.
  - Burning of solid waste in open dumps or incinerators, releases toxic gases and particulate matter into the air. Prolonged exposed to these gases can lead to health complications like respiratory and cardiovascular diseases.
- **Diseases:** Untreated solid waste attracts pests and disease vectors like flies, rats, and mosquitoes which can spread various diseases such as malaria, dengue fever, etc.
- **Occupational Hazards:** Waste management workers face occupational hazards and are at risk of injuries from sharp objects, exposure to hazardous substances, and the transmission of infectious diseases.

Solid Waste Management Processes

Mechanical Biological Treatment

- **Landfilling:** It involves burying waste in designated areas of land. The waste is placed in a pit, which is then covered with soil or other materials to prevent the spread of waste and reduce the risk of contamination to the surrounding environment.

Advantage of landfilling	Limitation of landfilling
No need for highly skilled employees.	Costly transportation to dumping land sites.
Low cost for waste treatment.	Choke the drainage system
High potential for gas recovery which can be used as a source of energy.	Major source of greenhouse gases.
Buying organic waste leads to net gain for the environment.	Need a large area of land for dumping.
	Birthplace for vermin, insects and may be the origin of various diseases.

- **Composting:** Composting is a natural process of decomposing organic matter, such as food and yard waste, into a nutrient-rich soil-like material. The process involves creating an environment that is favorable for microorganisms that break down the waste into humus, a nutrient-rich material that can be used to improve soil quality.

Advantage of Composting	Limitation of Composting
Augmentation in micronutrient deficiencies and improvement in soil texture.	Not suitable for all types of waste.
It maintains the soil health through increasing moisture-holding capacity and recycling nutrients into soil.	Large open land required.
It is very much straightforward and simple as well as cost-effective.	Composting plants emits methane, odor and flies.
Reduce the dependency on chemical fertilizer in the agriculture field.	Soil can be contaminated by entering toxic materials.
	Lack of awareness and proper marketing of compost material.

- **Vermicomposting:** It is a type of composting that uses earthworms to decompose organic waste. The earthworms feed on the organic waste and convert it into nutrient-rich vermicomposting, which can be used as a soil amendment.

Advantage of Vermicomposting

- Vermicomposting is a natural process that does not involve the use of chemicals or fossil fuels.
- It can be done indoors or outdoors, making it accessible to people with limited space.
- The process produces a high-quality, nutrient-rich compost that is ideal for gardening and agriculture.
- Vermicomposting can help reduce greenhouse gas emissions by diverting organic waste from landfills where it would produce methane, a potent greenhouse gas.

Limitation of Vermicomposting

- The process may not be suitable for large quantities of waste or waste that contains high levels of contaminants or toxins.
- Vermicomposting can attract pests, such as fruit flies or ants, if not managed properly.
- It can be time-consuming to harvest the vermicomposting and separate the worms from the compost.
- Vermicomposting requires a certain level of knowledge and management to ensure that the worms are healthy and the composting process is working efficiently.

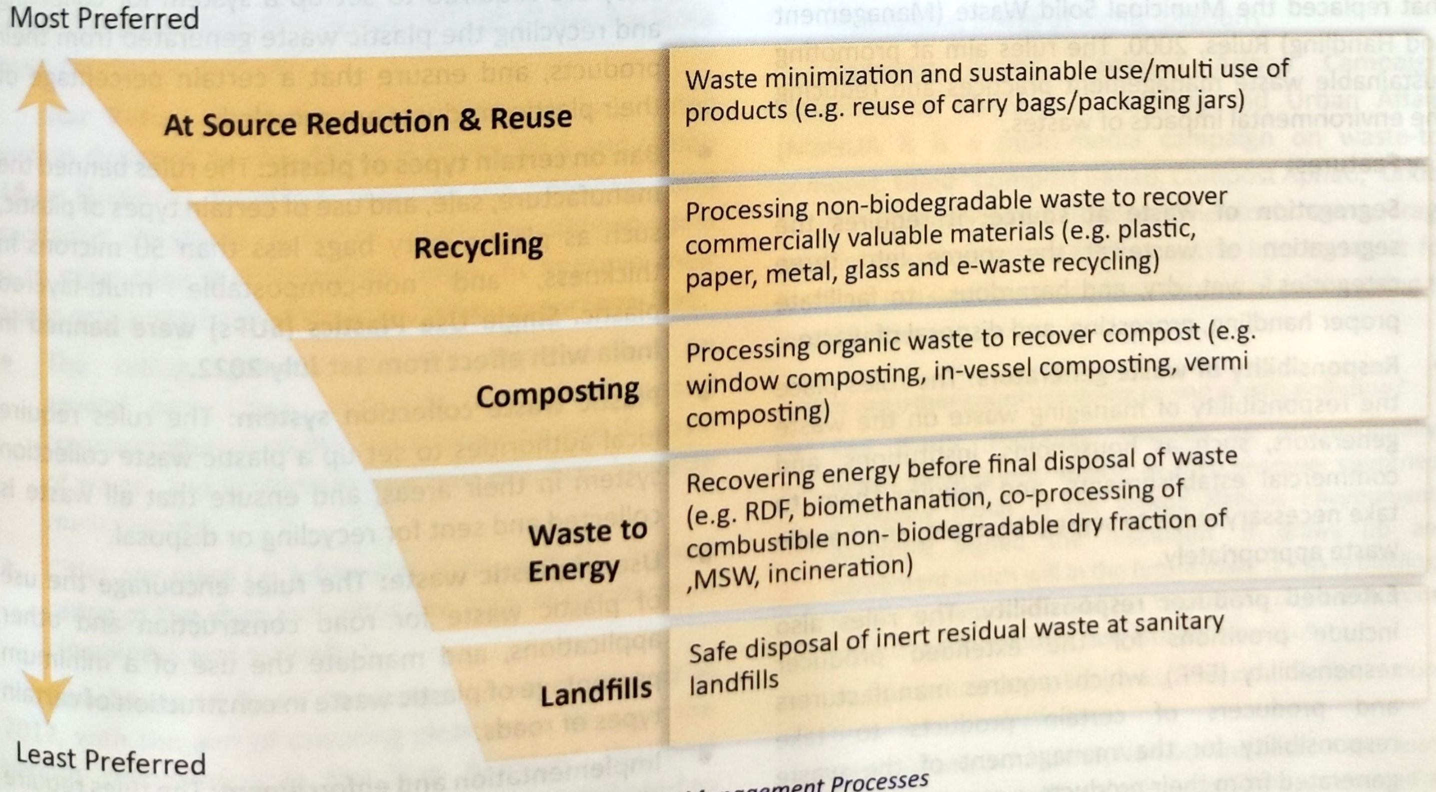
- **Anaerobic Digestion and Bio-methanation:** These processes involve decomposition of organic waste in the absence of oxygen to produce biogas. In the absence of oxygen, bacteria are used to break down organic matter. Bio-methanation is a sub-process within anaerobic digestion. It is used to enhance methane production and refine the biogas composition.

Thermal Treatment

- **Incineration:** In this process, organic and inorganic waste materials are burned at high temperatures to convert them into ash, gas, and heat. The process involves placing the waste into a specially designed furnace and burning it at a temperature of about 1,000 degrees Celsius. Incineration is primarily used for wastes that are not recyclable.

Compaction: It is a process of reducing the volume of solid waste by compressing it into smaller, more compact forms. It is done through machines such as compactors or balers. The process of compaction is used as a preliminary step in solid waste treatment processes, as it can make the waste easier to handle and transport.

- **Pyrolysis:** It is an alternative to the process of incineration. It involves thermal degradation of waste in the absence of air to produce char, pyrolysis oil and syngas (synthesis gas).



At Source Reduction & Reuse	Waste minimization and sustainable use/multi use of products (e.g. reuse of carry bags/packaging jars)
Recycling	Processing non-biodegradable waste to recover commercially valuable materials (e.g. plastic, paper, metal, glass and e-waste recycling)
Composting	Processing organic waste to recover compost (e.g. window composting, in-vessel composting, vermi composting)
Waste to Energy	Recovering energy before final disposal of waste (e.g. RDF, biomethanation, co-processing of combustible non- biodegradable dry fraction of ,MSW, incineration)
Landfills	Safe disposal of inert residual waste at sanitary landfills

Solid Waste Management Processes

Refuse-Derived Fuel (RDF): It is a type of fuel that is derived from municipal solid waste. RDF is created by processing MSW through mechanical, biological, or thermal treatment methods to remove non-combustible materials and extract combustible materials. The resulting RDF is a high-energy fuel and serves as an alternative to traditional fossil fuels.

Solid recovered fuel (SRF): It is produced from mainly commercial waste including paper, card, wood, textiles and plastic. It is a high-quality alternative to fossil fuel and has a higher calorific value than RDF. SRF is used in facilities such as cement kilns.

***Calorific Value**: It is the amount of heat released by a unit weight or unit volume of a substance during complete combustion

- **Gasification:** It is a chemical process that transforms a carbon-based material, such as MSW or biomass, into syngas without actually burning it. Plasma gasification uses plasma to convert organic matter into syngas.

Measures taken for Solid Waste Management in India

Solid Waste Management rules, 2016

Background: The Solid Waste Management Rules, 2016 are a set of regulations issued by the MoEFCC that replaced the Municipal Solid Waste (Management and Handling) Rules, 2000. The rules aim at promoting sustainable waste management practices and reducing the environmental impacts of wastes.

Key Features:

- **Segregation of waste at source:** It requires the segregation of waste at the source into three categories - wet, dry, and hazardous - to facilitate proper handling, processing, and disposal of waste.
- **Responsibility of waste generators**: The rules place the responsibility of managing waste on the waste generators, such as households, institutions, and commercial establishments, and require them to take necessary steps to segregate, store, and handle waste appropriately.
- **Extended producer responsibility**: The rules also include provisions for the extended producer responsibility (EPR), which requires manufacturers and producers of certain products to take responsibility for the management of the waste generated from their products.
- **Waste processing and disposal**: The rules mandate the processing and disposal of waste through environmentally sound methods, such as composting, recycling, and waste-to-energy conversion. Landfilling is only allowed as a last resort, and only for non-recyclable and non-recoverable waste.
- **Penalties and enforcement**: The rules provide for penalties and enforcement measures for non-compliance with the regulations.

Extended Producer Responsibility (EPR) is a policy approach that holds manufacturers responsible for the environmental impact of their products throughout their entire life cycle, including after the products are sold and consumed by consumers.)

The Plastic Waste Management Rules, 2016

Background: They were notified by the MoEFCC to address the issue of plastic waste in India. The rules replaced the earlier Plastic Waste (Management and Handling) Rules, 2011. It aims to improve the efficiency of plastic waste management and promote recycling.

Key Features:

- **Extended Producer Responsibility (EPR):** The rules introduced the concept of EPR, which makes producers and brand owners responsible for the management and recycling of their plastic waste. They are required to set up a system for collecting and recycling the plastic waste generated from their products, and ensure that a certain percentage of their plastic products are recycled.
- **Ban on certain types of plastic:** The rules banned the manufacture, sale, and use of certain types of plastic, such as plastic carry bags less than 50 microns in thickness, and non-compostable multi-layered plastic. **Single Use Plastics (SUPs) were banned in India with effect from 1st July 2022.**
- **Plastic waste collection system:** The rules require local authorities to set up a plastic waste collection system in their areas, and ensure that all waste is collected and sent for recycling or disposal.
- **Use of plastic waste:** The rules encourage the use of plastic waste for road construction and other applications, and mandate the use of a minimum percentage of plastic waste in construction of certain types of roads.
- **Implementation and enforcement:** The rules require state governments to set up a State Level Advisory Committee on plastic waste management, and establish a mechanism for monitoring and enforcing the rules

Plastic Waste Management (Amendment) Rules, 2022

- Mandatory targets on EPR, recycling of plastic packaging waste, reuse of rigid plastic packaging and use of recycled plastic content
- It banned the manufacture, import, stocking, distribution, sale and use of carry bags made of virgin or recycled plastic less than seventy-five microns. However, the ban will not apply to commodities made of compostable plastic.
- The CPCB, along with state pollution bodies, will monitor the ban, identify violations, and impose penalties already prescribed under the Environmental Protection Act.
- Local authorities have been directed to issue fresh commercial licenses with the condition that SUP items will not be sold on their premises, and existing commercial licenses will be cancelled if they are found to be selling these items.

Other Initiatives for Plastic Waste Management

- **National Dashboard on Elimination of Single Use Plastic and Plastic Waste Management (MoEFCC**: It aims to bring all stakeholders at one place and track the progress made for elimination of single use plastic and effective management of plastic waste.
- **Extended Producer Responsibility (EPR) Portal for Plastic Packaging (CPCB):** It aims to improve accountability, traceability, transparency and facilitate ease of reporting compliance to EPR Obligations by Producers, Importers and Brand-owners
- **Mobile App for Single Use Plastics Grievance Redressal (CPCB):** It aims to empower citizens to check sale/usage/manufacturing of single use plastics in their area.
- **Monitoring module for Single Use Plastics (CPCB)**
- **Industrial production of Graphene from Waste (G B Pant NIHE & NRDC):** It aims to promote more industries to come forward to up cycle plastic waste.

Swachh Survekshan: It is a survey conducted by the Ministry of Housing and Urban Affairs (MoHUA) to assess the cleanliness and sanitation status of urban areas in India. The survey was first launched in 2016 and has since been conducted annually.

Star Rating of Garbage-Free Cities: It is a rating system designed by the Ministry of Housing and Urban Affairs (MoHUA). It seeks to evaluate the cleanliness and sanitation standards of Indian cities. The ultimate goal is to encourage and incentivize cities to improve their waste management practices and become garbage-free.

- The rating system evaluates cities based on several parameters, including the collection and transportation of waste, the processing and disposal of waste, and innovation and best practices in waste management.
- Cities are rated on a five-star scale, with the highest rating of five stars indicating the highest standards of cleanliness and sanitation.

Swachhata Hi Sewa Campaign: It was launched in 2017, with the aim of ensuring cleanliness through the various stakeholders in the "Jan Andolan" (National Movement). The campaign's success can be attributed to its key highlights,

- **Sewa Diwas**, a nationwide volunteering service for cleanliness,
- **Samagra Swachhata,** which involved citizens, municipal bodies, SBM ambassadors, and corporates
- **Sarvatra Swachhata**, which included massive cleanliness, drives at iconic locations.

Compost Banao, Compost Apnao Campaign: Launched by Ministry of Housing and Urban Affairs (MoHUA it is a multi-media campaign on waste-to-compost, titled "Compost Banao, Compost Apnao," under Swachh Bharat Mission - (Urban). The aim is to encourage people to convert their kitchen waste into compost for fertilizer use and to reduce the amount of waste going to landfill sites.

What are other countries doing to end plastic pollution?

- **End Plastic Pollution: Towards an internationally legally binding instrument**: In 2022, member countries (including India) of the United Nations Environment Assembly signed the resolution. It draws up an agreement which will in the future make it legally binding for the signatories to address the full life of plastics from production to disposal, and end plastic pollution.
- **Bangladesh:** In 2002, Bangladesh became the first nation to outlaw thin plastic bags.
- **New Zealand:** In July 2019, New Zealand became the most recent nation to outlaw plastic bags. China announced a phased-in ban on plastic bags in 2020.
- **Other nations:** As of July 2019, 68 countries have plastic bag bans with varying degrees of enforcement.

E-WASTE

According to the Global E-waste Statistics Partnership (GESP), Electronic waste, or e-waste, refers to all items of electrical and electronic equipment (EEE) and its parts that have been discarded by its owner as waste without the intent of re-use.

Types of E-Waste

- **Large household appliances:** This includes refrigerators, washing machines, air conditioners, and other large appliances.
- **Small household appliances:** This includes vacuum cleaners, toasters, coffee makers, and other small appliances.
- **IT and telecommunications equipment:** This includes computers, laptops, printers, telephones, and other communication devices.
- **Consumer equipment:** This includes televisions, radios, and other audiovisual equipment.
- **Lighting equipment:** This includes light bulbs and lamps.
- **Electrical and electronic tools:** This includes drills, saws, and other tools that run on electricity.

Trends in E-waste

According to Global E-waste Monitor Report 2020,

- **Total Waste Generated**: In 2019, the world generated 53.6 million metric tons of e-waste.
- **Collection and Recycling:** Only 17.4% of e-waste generated in 2019 was collected and recycled through formal channels, such as take-back and recycling programs.
- **Categories:** Electronic devices with the highest e-waste generation in 2019 were small equipment (17.4 million metric tons), followed by large equipment (13.1 million metric tons), and temperature exchange equipment (10.8 million metric tons).
- **Country-wise e-waste generation:** China generated the highest amount of e-waste in 2019, at 10.1 million metric tons, followed by the United States, India, and Japan.
- **Per capita e-waste generation:** The highest per capita e-waste generators were in Europe, with Norway generating the highest amount of e-waste per capita, at 26.0 kg/person, followed by Switzerland (22.2 kg/person) and Iceland (19.0 kg/person).
- **India:**
  - In 2019, India generated 3.2 million metric tons of e-waste.
  - India's e-waste generation is projected to reach 5.2 million metric tonnes by 2025, with an annual growth rate of 8%

Toxic Elements in E-waste

Pollutant	Use and Impact
Lead (Pb)	Lead is commonly used in cathode ray tubes (CRTs) found in older televisions and computer monitors. Exposure to lead can cause damage to the nervous system, brain development problems, and anemia.
Mercury (Hg)	Mercury is used in fluorescent lamps, switches, and batteries. Exposure to mercury can cause neurological and developmental problems, kidney damage, and respiratory problems.
Cadmium (Cd)	Cadmium is used in rechargeable batteries and some types of electronic components. Exposure to cadmium can cause kidney damage, lung cancer, and bone disease.
Polybrominated diphenyl ethers (PBDEs)	PBDEs are flame retardants used in plastics, foams, and textiles. Exposure to PBDEs can cause developmental problems, thyroid disorders, and liver damage.
Polyvinyl chloride (PVC)	PVC is a common plastic used in electronic components and cables. PVC can release toxic chemicals during production and disposal, and exposure to PVC can cause respiratory problems and cancer.

Impacts of E-waste

- **Environmental impacts:** Improper disposal of e-waste can lead to environmental pollution, such as soil contamination, air pollution, and water pollution. This is due to the presence of hazardous substances such as lead, mercury, cadmium, and brominated flame retardants, which can cause long-term damage to ecosystems and human health.
- **Human health impacts:** Exposure to hazardous substances found in e-waste can cause serious health problems such as cancer, birth defects, neurological damage, and respiratory illnesses. This is especially a concern for those who are involved in the informal recycling of e-waste, such as waste pickers and informal recyclers.

- **Economic impacts:** E-waste can contain valuable materials such as gold, silver, copper, and other metals that can be recovered and recycled. However, if e-waste is not properly managed, these valuable resources are lost, and the potential economic benefits of recycling are not realized.
- **Social impacts:** The informal recycling of e-waste in developing countries is often done by marginalized groups, such as waste pickers and informal recyclers. This can lead to social and economic inequality, as well as exploitation and unsafe working conditions.

Global E-waste Management

- **Basel Convention and E-waste Management:** The Basel Convention is an international treaty that aims to prevent the movement of hazardous waste from developed countries to developing countries for the purpose of disposal. The treaty was adopted in 1989 and has been ratified by 187 countries, including India. The Basel Convention started to address e-waste issues since 2002, when The Mobile Phone Partnership Initiative (MPPI) was adopted.
    - **The Mobile Phone Partnership Initiative (MPPI):** It was launched in 2022 under the Basel Convention. It was developed to address the growing problem of e-waste generated by mobile phones and to promote sustainable practices in the mobile phone industry. It is a voluntary partnership between governments, mobile phone manufacturers, and other stakeholders in the industry.
    - **Nairobi Declaration on the Environmentally Sound Management of Electrical and Electronic Waste** It was adopted at the eighth meeting of the Conference of the Parties to the Basel Convention in 2006. Parties to the Convention agreed to develop policies and strategies aimed at improving the environmentally responsible collection, proper separation from household waste, repair, recycling, and final disposal of electronic waste (e-waste). Additionally, they committed to preventing the illegal trafficking of e-waste.

R2 Code of Practices

R2 stands for Responsible Recycling. R2 Code of Practices is a standard specifically created for the electronics recycling industry by Sustainable Electronics Recycling International (SERI).

Legal, Policy, and Institutional Framework for Managing E-waste in India

The Ministry of Environment and Forests introduced the E-Waste (Management and Handling) Rules in 2011, which mandated the creation of e-waste management systems and provided guidelines for the disposal and recycling of electronic products. It also introduced Extended Producer Responsibility for the first time in India.

In 2016, these rules were revised and strengthened with the introduction of the E-Waste Management Rules 2016. It expanded the scope of the regulations and increased the responsibility of manufacturers and producers to manage their e-waste.

E-Waste (Management) Rules, 2022

Key Features:

- **Modified EPR**: Introduced the concept of a modified Extended Producer Responsibility (EPR). It mandates that manufacturers, importers, and brand owners of electronic equipment will be responsible for the collection and disposal of e-waste generated from their products. They must set up collection centers for e-waste, provide financial support for recycling, and ensure proper disposal of hazardous waste.
- **Applicability:** Applicable to every manufacturer, producer, consumer, bulk consumer, collection centers, dealers, e-retailer, refurbisher, dismantler and recycler.
- **Online Registration:** All the manufacturer, producer, refurbisher and recycler are required to register on portal developed by CPCB.
- **E-Waste Recycling targets:** Producers of notified Electrical and Electronic Equipment (EEE), have been given annual E-Waste Recycling targets based on the given annual E-Waste Recycling targets based on the generation from the previously sold EEE or based on sales of EEE. It sets a collection target of 30% of the waste generated in the previous year for the first year of implementation, which will increase by 10% every year thereafter
- **Extended Producer Responsibility (EPR) Certificate:** Provision for generation and transaction of EPR Certificate has been introduced.
- **Scope of Electronic Goods:** Management of solar PV modules /panels/ cells added in new rules.
- **Restrictions:** Puts restriction on lead, mercury and other hazardous substances beyond the maximum prescribed concentration to be used in EEE.

- **Deposit Refund Scheme:** Introduced a deposit refund scheme, which will incentivize consumers to return their old electronic products to manufacturers or authorized collection centers. The deposit will be refunded when the e-waste is properly disposed of.
- **Roles and Responsibilities**
    - **Role of manufacturers:** will make the end product recyclable
    - **Role of State Governments:** Will designate industrial space for e-waste dismantling and recycling facilities, undertaking industrial skill development and establishing measures for protecting the health and safety of workers engaged in the dismantling and recycling facilities for e-waste.
    - **Role of Central Pollution Control Board (CPCB):** Will conduct random sampling of electrical and electronic equipment placed on the market to monitor and verify the compliance of reduction of hazardous substances provisions.

The E-Waste (Management) Rules, 2023: It seeks to amend E-waste (Management) Rules 2022 and adds two substances to the Schedule II of E-waste (Management) Rules 2022, which contains the list of exempted elements under the E-Waste Management Rules. Two elements are:

- Cadmium and lead in Solar panels/cells, and solar Photovoltaic panels/cells/ modules.
- Lead in Medical Devices (except for all implanted and infected products).

DO YOU KNOW?

An E-Waste Clinic is a type of facility or program that provides services related to the management and recycling of electronic waste or e-waste. India's first E-waste Clinic opened in Bhopal.

Best Practices:

- **European Union (EU) model:** The EU model for managing e-waste includes the implementation of Extended Producer Responsibility (EPR) programs, which hold producers responsible for the disposal of their products at the end of their life cycle. The EU model also includes a ban on the export of hazardous waste, including e-waste, to developing countries.
- **Japanese model:** The Japanese model for managing e-waste includes a focus on recycling and reuse of electronic waste, with a goal of achieving zero e-waste generation. The model includes a combination of government regulations, voluntary initiatives, and public-private partnerships to promote sustainable e-waste management practices.
- **South Korean model:** The South Korean model for managing e-waste includes a comprehensive e-waste management system that includes the establishment of collection points for e-waste, a national e-waste recycling fund, and a ban on the disposal of e-waste in landfills.
- **NOKIA's Take Back Initiative in India:** Nokia has implemented a take-back program in India, which allows customers to return their end-of-life Nokia products for safe and environmentally friendly disposal.

BIOMEDICAL WASTE

According to the World Health Organization (WHO), biomedical waste, also known as healthcare waste, is defined as any waste generated during diagnosis, treatment, or immunization of human beings or animals or in research activities in these fields, or in the production or testing of biologicals. It includes wastes like human anatomical waste, animal waste, microbiology & biotechnology waste, discarded medicines and cytotoxic drugs, soiled waste, solid waste, liquid waste, incineration ash, chemical wastes.

Status of Biomedical Waste

Global:

According to WHO,

- **Global biomedical waste generation:** approximately 5.9 million tons of biomedical waste are generated annually worldwide.
- **Healthcare facility-generated waste:** approximately 85% of biomedical waste is generated from healthcare facilities, including hospitals, clinics, and nursing homes.
- **Low- and middle-income countries:** In low- and middle-income countries, up to 64% of healthcare facilities lack basic waste management services.
- **Occupational hazards:** healthcare workers globally are at risk of infection from needle stick injuries alone, with an estimated 16 billion injections administered each year.
- **Impact of COVID-19:** The COVID-19 pandemic has led to a significant increase in the generation of biomedical waste, including PPE, gloves, masks, and other medical supplies. Some countries have reported a tenfold increase in healthcare waste generation during the pandemic.

India

In 2018, the Central Pollution Control Board (CPCB) conducted a survey of 2,468 healthcare facilities across India and found that approximately 590 tonnes of biomedical waste were generated per day. 85% of the biomedical waste generated was non-hazardous, 15% was hazardous, and 2% was in the form of sharps waste.

Types of Bio-Medical waste

There are eight different types of biomedical waste, as categorized by the World Health Organization (WHO):

- **Infectious Waste:** Waste that contains pathogens or microorganisms that can cause disease in humans, such as discarded cultures, swabs, and tissues from patients with infectious diseases.
- **Pathological Waste:** Waste that consists of human or animal tissues, organs, and body parts, including biopsy specimens and anatomical parts that have been removed during surgery or autopsy.
- **Sharps Waste:** Waste that includes any object or device that can puncture or lacerate the skin, such as needles, syringes, scalpels, and broken glass.
- **Chemical Waste:** Waste that contains chemicals that may be toxic, corrosive, or flammable, such as solvents, disinfectants, and heavy metals.
- **Radioactive Waste**: Waste that contains radioactive materials, such as nuclear medicine waste, and waste from diagnostic and therapeutic procedures involving radioisotopes.
- **Pharmaceutical Waste**: Waste that includes expired or unused drugs, vaccines, and other medications.
- **Genotoxic Waste:** Waste that contains genotoxic or mutagenic agents, such as cytotoxic drugs used in chemotherapy, which can cause damage to DNA.
- **Other Healthcare Waste:** Waste that includes non-infectious and non-hazardous waste generated in healthcare facilities, such as packaging materials, food waste, and office supplies.

Toxicity of Bio-Medical Waste

The Bio-medical waste is considered hazardous as it contains various toxic elements and substances, such as:

- **Heavy metals:** Biomedical waste can contain heavy metals such as lead, mercury, cadmium, and chromium. These metals can accumulate in the environment and have toxic effects on human health, including damage to the nervous system, kidneys, and liver.
- **Chemicals:** Biomedical waste can also contain various chemicals such as disinfectants, solvents, and pesticides. These chemicals can be toxic to human health and the environment, causing skin irritation, respiratory problems, and even cancer.
- **Radioactive materials:** Biomedical waste can contain radioactive materials, such as radioisotopes used in medical imaging and cancer treatment. These materials can be highly toxic and pose a risk to both human health and the environment.
- **Pathogens**: Biomedical waste can contain pathogens such as bacteria, viruses, and fungi. These pathogens can cause a range of diseases and infections, which can be harmful to human health.

Impacts of Bio-medical Waste

- **Environmental impacts:** Biomedical waste can have adverse effects on the environment, particularly on soil, water, and air quality. For example, the improper disposal of infectious waste can lead to the spread of pathogens and contaminate soil and groundwater. Pharmaceutical waste can also contaminate water sources and harm aquatic life. Furthermore, the incineration of biomedical waste can release harmful pollutants into the air.
- **Public health impacts:** Biomedical waste poses a significant risk to public health, particularly to healthcare workers who are in close contact with the waste. Exposure to infectious waste can lead to the transmission of diseases, while sharps waste can cause injuries and the transmission of blood-borne pathogens. Furthermore, improper disposal of pharmaceutical waste can lead to drug-resistant bacteria and contamination of the food chain.
- **Social impacts:** The social impacts of biomedical waste include the stigmatization of individuals and communities associated with the waste. The perception that biomedical waste is dangerous and contagious can lead to discrimination and social exclusion.

Global Frameworks for Managing Bio-medical Waste

1. **Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal:** This convention aims to reduce the movement of hazardous waste between countries and promote the safe management of such waste.

2. **Stockholm Convention on Persistent Organic Pollutants:** This convention focuses on reducing and eliminating the production and use of persistent organic pollutants (POPs) which are harmful to human health and the environment.
3. **World Health Organization (WHO) Guidelines on Safe Management of Wastes from Health-Care Activities:** These guidelines provide a framework for managing healthcare waste, including biomedical waste, to prevent adverse health and environmental impacts.
4. **United Nations Environment Programme (UNEP) Global Mercury Partnership:** This partnership aims to reduce the global use and release of mercury, which is commonly found in biomedical waste.
5. **International Organization for Standardization (ISO) 14001 Environmental Management System:** This standard provides a framework for organizations to develop and implement an environmental management system, including the management of biomedical waste.

Legal, Policy, and Institutional Framework for Managing Bio-Medical Waste in India

India has an extensive framework of Statuary laws, comprehensive policy, and robust Institutional framework to manage Bio-Medical Waste.

- **Biomedical Waste (Management and Handling) Rules, 1998:** In India, the first set of rules for biomedical waste management was introduced in 1998. These rules were called the "Biomedical Waste (Management and Handling) Rules, 1998." The main objective of these rules was to regulate the generation, collection, storage, transportation, and disposal of biomedical waste in a safe and environmentally friendly manner.
- **Biomedical Waste (Management and Handling) Rules, 2000:** In 2000, the rules were amended to make them more comprehensive and to address the growing concerns about the management of biomedical waste. The amended rules were called the "Biomedical Waste (Management and Handling) Rules, 2000."

Bio-Medical Waste Management Rules, 2016

Key Features

- **Segregation and Storage:** The waste should be segregated at the point of generation into categories such as human anatomical waste, animal waste, microbiological and biotechnology waste, sharps waste, and so on. The waste should be stored in color-coded containers, and the storage area should be well-ventilated, with proper labeling and signage.
- **Transportation:** The transportation of biomedical waste should be done only by authorized persons or agencies, using dedicated vehicles with proper signage, and the waste should be transported within 24 hours of generation.
- **Treatment and Disposal:** The biomedical waste should be treated and disposed of in an environmentally sound manner, using approved technologies such as incineration, autoclaving, microwaving, or chemical treatment. Disposal should be in landfills specifically designated for biomedical waste disposal.
- **Record Keeping:** Healthcare facilities generating biomedical waste should maintain a record of the waste generated, stored, transported, and disposed of, including details such as the type of waste, quantity, and destination.
- **Training and Awareness:** Healthcare workers and staff should receive regular training on the proper handling and disposal of biomedical waste.

Bio medical waste management (amendment) Rules 2018

The Biomedical Waste Management Rules, 2016 were amended 2018 to strengthen the management and handling of biomedical waste in India.

Key Features

- **Expansion of Scope:** The scope of the rules was expanded to cover all healthcare facilities, including veterinary hospitals, clinics, animal houses, and laboratories, as well as blood banks, medical research facilities, and home healthcare facilities.
- **Categorization of Waste:** The categorization of biomedical waste was revised to include four new categories, namely, solid waste, liquid waste, chemical waste, and hazardous waste.
- **Color Coding and Type of Containers:** The color-coding and type of containers were revised to ensure proper segregation and safe handling of biomedical waste.
- **Barcoding:** Barcoding of biomedical waste bags, containers, and vehicles were introduced to ensure proper tracking and monitoring of waste from its generation to final disposal.
- **Responsibility of Generators:** The responsibility of generators of biomedical waste was clearly defined, including the requirement to register with the State Pollution Control Board, maintain records, and

ensure proper segregation, packaging, and storage of waste.

- **Standard Operating Procedures:** Standard Operating Procedures (SOPs) for the management and handling of biomedical waste were revised and standardized across all healthcare facilities to ensure proper compliance and adherence to the rules.

Best Practice: Singapore Model

Singapore has implemented a successful waste-to-energy program that involves the incineration of biomedical waste and other types of waste to generate electricity. It gives a win-win situation for both Environment sustainability and Economic Development in an integrated system.

CHAPTER

18

PERSISTENT ORGANIC POLLUTANTS

PERSISTENT ORGANIC POLLUTANTS (POPS)

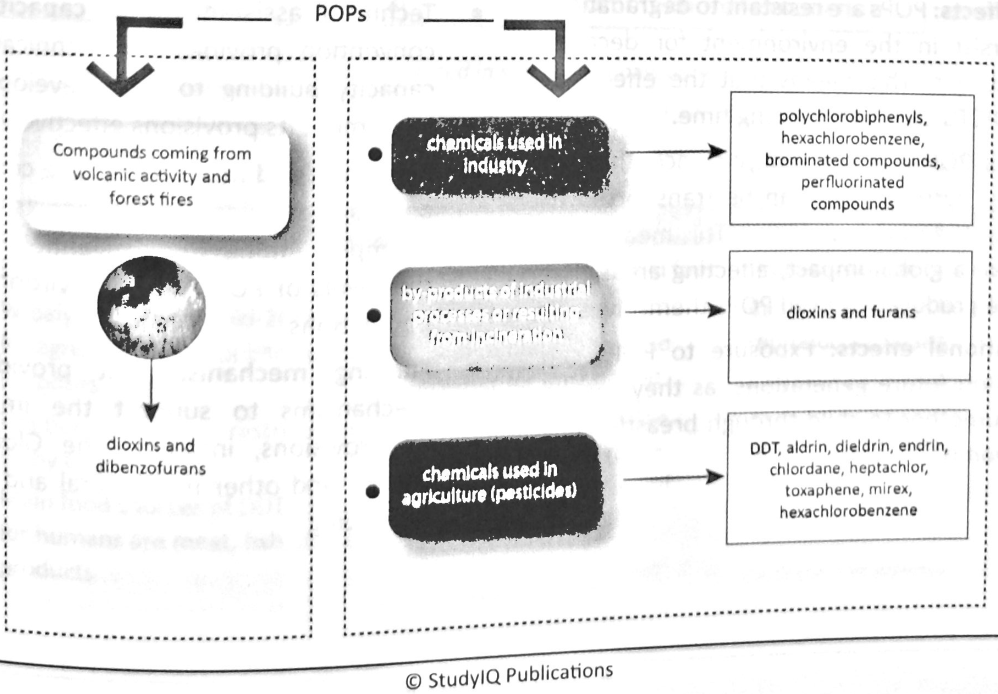
Persistent Organic Pollutants (POPs) are a group of toxic chemicals that persist in the environment for a long time and can cause harm to human health and the environment. They are organic compounds that resist degradation and can accumulate in the food chain, particularly in fatty tissues of animals and humans. Examples of POPs include polychlorinated biphenyls (PCBs), dioxins, furans, and some pesticides

Characteristics of POPs

- **Persistence**: POPs are resistant to degradation and can persist in the environment for long periods of time, ranging from years to decades or even centuries.
- **Bioaccumulation and Biomagnification:** POPs can accumulate in the fatty tissues of animals and humans. They can biomagnify as they move up the food chain. This can result in higher concentrations of POPs in animals higher up in the food chain, including humans.
- **Long-range transport:** POPs can travel long distances through air and water currents, and can be transported to areas far from their original source. This means that they can have a global impact, affecting areas that may not have produced or used POPs themselves
- **Toxicity:** Many POPs are highly toxic to humans and wildlife, even at low levels of exposure. They can cause a range of health problems, including cancer, reproductive and developmental problems, immune system damage, and endocrine disruption.
- **Chemical stability:** POPs are chemically stable, meaning that they do not break down easily, and can resist degradation from sunlight, heat, and chemical processes
- **Lipophilicity:** POPs have a strong affinity for fat, which means that they can accumulate in the fatty tissues of animals and humans. This can result in higher concentrations of POPs in animals with higher fat content, such as marine mammals.

Sources Of POPs

- **Industrial processes:** POPs are produced as by-products in various industrial processes, such as the production of certain chemicals, plastics, and pesticides.


POPs
Compounds coming from volcanic activity and forest fires
dioxins and dibenzofurans
chemicals used in industry
polychlorobiphenyls, hexachlorobenzene, brominated compounds, perfluorinated compounds
by-products of industrial processes or resulting from incineration
dioxins and furans
chemicals used in agriculture (pesticides)
DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, toxaphene, mirex, hexachlorobenzene

- **Agricultural practices:** The use of pesticides, herbicides, and fertilizers in agriculture can lead to the release of POPs into the environment. POPs can also be generated by the burning of agricultural waste and the use of contaminated animal feed.
- **Waste disposal:** Improper disposal of waste, such as burning or dumping of hazardous waste, can release POPs into the environment. Landfills are also a source of POPs as they can contaminate the soil and groundwater.
- **Transportation:** POPs can be released into the atmosphere during the combustion of fossil fuels in vehicles and airplanes.
- **Consumer products:** Some consumer products, such as electronics, contain POPs as flame retardants or plasticizers.
- **Natural sources:** Some POPs, such as dioxins, are also produced naturally by volcanic eruptions and forest fires.

Effects of POPs

- **Health effects:** Exposure to POPs has been linked to a range of health problems, including cancer, reproductive and developmental problems, immune system damage, and endocrine disruption. Some POPs can also affect the nervous system, leading to cognitive and behavioral problems
- **Environmental effects:** POPs can harm wildlife, particularly aquatic animals and birds, and can disrupt ecosystems. They can accumulate in the food chain, with higher concentrations found in animals higher up in the food chain.
- **Long-term effects:** POPs are resistant to degradation, and can persist in the environment for decades or even centuries. This means that the effects of exposure to POPs can last for a long time.
- **Global effects:** POPs can travel long distances through air and water currents, and can be transported to areas far from their original source. This means that they can have a global impact, affecting areas that may not have produced or used POPs themselves
- **Inter-generational effects:** Exposure to POPs can have effects on future generations, as they can be passed from mother to child through breastfeeding and in the womb
- **Economic effects:** The costs associated with cleaning up contaminated sites and treating health problems related to exposure to POPs can be significant, leading to economic impacts on communities and countries.

Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants is a global treaty to protect human health and the environment from POPs. The Convention was adopted in 2001 and entered into force in 2004. There are 186 parties to the Convention and 152 signatories.

Key Features

- **List of chemicals:** The convention currently regulates 31 chemicals as POPs under three annexes.

Annex A-	**Chemicals to be eliminated with specific exemptions**
Annex B -	**Chemicals to be restricted**
Annex C -	**Minimization of unintentional releases of listed chemicals**

- **Control measures:** The convention requires parties to take measures to control and reduce the release of POPs into the environment. This includes measures to minimize or eliminate the production and use of POPs, as well as the environmentally sound management of POPs waste.
- **National Action Plans**: For unintentionally produced POPs, the Stockholm Convention requires countries to develop national action plans to address releases and to apply "Best Available Techniques" to control them
- **Technical assistance and capacity building:** The convention provides for technical assistance and capacity building to help developing countries to implement its provisions effectively.
- **Reporting and monitoring:** The convention requires parties to provide regular reports on their progress in implementing the convention, and to monitor the levels of POPs in the environment and human populations
- **Funding mechanisms:** It provides for funding mechanisms to support the implementation of its provisions, including the Global Environment Facility and other multilateral and bilateral sources of funding.

Annex 1 (Elimination)

- Aldrin ●
- Chlordane ●
- Chlordecone ●
- Decabromodiphenyl ether (commercial mixture, c-decaBDE) ▲
- Dicofol ●
- Dieldrin ●
- Endrin ●
- Heptachlor ●
- Hexabromobiphenyl ▲
- Hexabromocyclododecane (HBCDD) ▲
- Hexabromodiphenyl ether and heptabromodiphenyl ether<br/>(commercial octabromodiphenyl ether) ▲
- Hexachlorobenzene (HCB) ● ▲
- Hexachlorobutadiene (HCBD) ▲
- Alpha hexachlorocyclohexane ●
- Beta hexachlorocyclohexane ●
- Lindane ●
- Mirex ●
- Pentachlorobenzene (PeCB) ● ▲
- Pentachlorophenol and its salts and esters (PCP) ●
- Polychlorinated biphenyls (PCB) ▲
- Polychlorinated naphthalenes (PCNs) ▲
- Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds ▲
- Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds ▲
- Short-chained chlorinated paraffins ▲
- Technical endosulfan and its related isomers ●
- Tetrabromodiphenyl ether and pentabromodiphenyl ether <br/>(commercial pentabromodiphenyl ether) ▲
- Toxaphene ●

Annex B (Restriction)

- DDT ●
- Perfluorooctane sulfonic acid (PFOS), its salts and<br/> perfluorooctane sulfonyl fluoride (PFOS-F) ● ▲

Annex C (Unintentional production)

- Hexachlorobenzene (HCB) ■
- Hexachlorobutadiene (HCBD) ■
- Pentachlorobenzene (PeCB) ■
- Polychlorinated biphenyls (PCB) ■
- Polychlorinated dibenzo-p-dioxins (PCDD) ■
- Polychlorinated dibenzofurans (PCDF) ■
- Polychlorinated naphthalenes (PCNs) ■

● Pesticide ▲ Industrial chemical ■ Unintentional Production

All POPs listed in stockholm Convention

Some Important POPs

POP	Important Facts	Impact on Environment	Impact on Human Health
DDT	Organochlorine insecticide Widely used in the mid-20th century for agricultural and public health purposes Has been banned or restricted in many countries Main food sources of DDT exposure for humans are meat, fish, and dairy products	Can Bioaccumulate in food chain Can remain in soil and water for long period Disrupt the endocrine system and affect the reproductive health of animals	Probable human carcinogen Can interfere with hormones and reproductive health Can have neurological effects Can suppress immune system.

POP	Important Facts	Impact on Environment	Impact on Human Health
Endosulfan	Organochlorine pesticide	Highly toxic to fish, birds & insects Soil and water contamination	Potent neurotoxin that can affect the nervous system Can interfere with the reproductive system Can disrupt endocrine system Possible human carcinogen
Chlorinated hydrocarbons	Widely used as insecticides, herbicides, fungicides, and industrial solvents	Can bioaccumulate Highly toxic to fish, birds & insects Soil and water contamination	Potent neurotoxin that can affect the nervous system Can interfere with the reproductive system Can disrupt endocrine system Possible human carcinogen
Perfluoroalkyl Acids (PFAAs)	Group of synthetic chemicals Used wide range of industrial and consumer products like non-stick cookware, waterproof clothing, carpets, firefighting foam, and electronic components.	Can bioaccumulate Highly toxic to fish, birds & insects Soil and water contamination	Liver damage Thyroid disease Possible human carcinogen Can interfere with reproductive system.

Rules to Regulate POPs in India

Central Government had, in exercise of powers conferred under the Environment (Protection) Act, 1986 published the rules for regulating the POPs in India- 'Regulation of Persistent Organic Pollutants Rules', 2018

Salient Features of the Rules

- **Prohibition on manufacture, etc. of chemicals.** - The manufacture, trade, use, import and export of the following seven chemicals are all be prohibited-
    - Chlordecone
    - Hexabromobiphenyl
    - Hexabromodiphenyl ether and heptabromodiphenyl ether (commercial octa-BDE)
    - Tetrabromodiphenyl ether and pentabromodiphenyl ether (commercial penta-BDE)
    - Pentachlorobenzene
    - Hexabromocyclododecane
    - Hexachlorobutadine.
- **Declaration by Occupier.** - The Occupier needs to declare the total quantity of the chemicals which are in use and their stockpiles
- **Occupier not to drain or discharge chemicals.** - The Occupier is prohibited from draining/disposing/ discharging the chemicals directly or indirectly in effluent treatment plant, sewage treatment plant, onto any land, in public sewers, in inland surface water or in marine coastal areas.
- **Disposal of waste.** - The waste containing chemicals shall be disposed of as per the provisions of the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016.
- **Use of chemicals for scientific purpose.** - The chemicals mentioned above may be used, sold or imported in quantities as required for research and development activities.

HAZARDOUS WASTE

Hazardous waste refers to any material or substance that poses a threat to human health or the environment. This can include chemicals, biological materials, radioactive materials, and other substances that can cause harm or pollution if not properly handled and disposed.

Sources of Hazardous Waste

- **Industrial activities:** Many industries generate hazardous waste as part of their production processes. This can include chemicals, solvents, and heavy metals used in manufacturing, mining, and other industrial processes.

- **Healthcare facilities:** Medical waste, such as used syringes, pharmaceuticals, and chemicals, is considered hazardous waste and needs to be properly disposed of to prevent contamination and harm.
- **Laboratories:** Laboratories generate a variety of hazardous waste, including chemicals, biological materials, and radioactive substances.
- **Household waste:** Household hazardous waste includes items such as batteries, fluorescent light bulbs, and cleaning products that contain toxic or hazardous chemicals.
- **Construction and demolition:** Construction and demolition activities generate hazardous waste such as asbestos, lead paint, and other chemicals that need to be properly handled and disposed of
- **Agriculture:** Pesticides and fertilizers used in agriculture can be hazardous to human health and the environment

Global Measures to Address Hazardous Waste

Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in 1989 and it came into force in 1992. It is the most comprehensive global environmental agreement on hazardous wastes and other wastes. It aims to protect human health and the environment against the adverse effects resulting from the generation, transboundary movements and management of hazardous wastes and other wastes. There are 175 parties to the Convention.

Key features

- **Definition of hazardous waste:** The Basel Convention provides a comprehensive definition of hazardous waste, including any waste that is toxic, explosive, flammable, corrosive, infectious, or ecotoxic.
- **Prohibition of export:** The convention prohibits the export of hazardous waste from developed countries to developing countries, as well as exports between developing countries, without the consent of the importing country.
- **Prior informed consent (PIC):** The convention requires countries to obtain prior informed consent from the importing country before exporting hazardous waste. The PIC procedure is a mechanism for formally obtaining and disseminating the decisions of importing parties on their willingness to receive future shipments of Hazardous chemicals.
- **Notification procedure:** The convention establishes a notification procedure for countries to inform each other of their hazardous waste exports and imports.
- **Environmentally sound management:** The convention requires countries to ensure that hazardous waste is managed in an environmentally sound manner, including the reduction of waste generation, recycling, and the safe disposal of waste.
- **Liability and compensation:** The convention establishes a liability and compensation regime for damage caused by the transboundary movement of hazardous waste.
- **Technology transfer:** The convention encourages technology transfer to enable developing countries to manage hazardous waste in an environmentally sound manner.
- **Capacity building:** The convention provides for capacity building and technical assistance to help countries implement the convention's provisions.

Rotterdam Convention

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade is an international treaty designed to facilitate informed decision-making by countries with regard to trade in hazardous chemicals. It was adopted in 1998 and came into force in 2004. There are 163 parties and 72 signatories. India is a member to the Convention.

Key features

- **Prior informed consent:** The convention establishes a prior informed consent (PIC) procedure for certain hazardous chemicals and pesticides in international trade. This procedure ensures that importing countries are informed about the potential hazards of the chemicals and pesticides before they are imported.
- **Application of PIC:** The PIC Regulation applies to banned or severely restricted chemicals, containing industrial chemicals, pesticides and biocide. For example, benzene, chloroform, atrazine and permethrin. The export of these chemicals is subject to two types of requirements: export notification and explicit consent
- **National implementation:** The convention requires countries to take appropriate measures to implement its provisions, including legislation, regulations, and administrative measures.

Hong Kong Convention

The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships is a treaty adopted in 2009 by the International Maritime Organization (IMO). It provides a globally applicable framework for the safe and environmentally sound recycling of ships. The aim is to ensure that ships are recycled in a way that is safe for workers and the environment.

Indian Initiatives for Regulating Hazardous Waste

Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016

The hazardous waste management rules in India were first introduced in 1989 and have been revised several times since then. The latest version of these rules is the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016. The salient features of these rules are as follows:

- **Definition of hazardous waste:** The rules provide a comprehensive definition of hazardous waste and classify it into different categories based on its properties.
- **Authorization for hazardous waste generators:** Any person or organization generating hazardous waste needs to obtain authorization from the State Pollution Control Board or Pollution Control Committee.
- **Manifest system:** The rules require the use of a manifest system for the transportation of hazardous waste. The manifest must contain details of the waste, the generator, the transporter, and the facility where it will be treated or disposed of.
- **Treatment and disposal of hazardous waste:** The rules provide guidelines for the treatment and disposal of hazardous waste. The aim is to minimize the environmental impact of hazardous waste and ensure that it is disposed of safely.
- **Responsibility of the generator:** The generator of hazardous waste is responsible for ensuring that the waste is treated and disposed of in an environmentally sound manner.
- **Financial responsibility:** The rules require the generator of hazardous waste to provide financial assurance for the safe disposal of the waste.
- **Penalties:** The rules provide for penalties in case of non-compliance. The penalties include fines, imprisonment, and cancellation of authorization.
- **Transboundary movement of hazardous waste:** The rules regulate the transboundary movement of hazardous waste, ensuring that it is done in a safe and environmentally sound manner.

The Ship Recycling Act 2019

The Recycling of Ships Act 2019 is an Indian legislation that regulates the recycling of ships and aims to ensure environmentally sound and safe recycling of ships in India. Some of the salient features of the Act are:

- **Requirement for ship recycling facilities:** The Act requires that ship recycling facilities be authorized and meet certain standards in order to operate in India.
- **Environmental clearance:** Ship recycling facilities are required to obtain environmental clearance from the Ministry of Environment, Forest and Climate Change before commencing operations.
- **Inventory of hazardous materials:** Ships that are to be recycled in India must have an inventory of hazardous materials on board, which must be submitted to the recycling facility before the ship arrives.
- **Safety and health standards:** The Act set out standards for the safety and health of workers in ship recycling facilities, including provisions for training, protective equipment, and medical facilities
- **Penalties:** The Act provides for penalties for non-compliance with its provisions, including fines and imprisonment.
- **Ship Recycling Plan:** The Act requires the shipowner to submit a Ship Recycling Plan to the relevant authorities, detailing how the ship will be recycled in a safe and environmentally sound manner.
- **Certification:** The Act requires that ship recycling facilities be certified by the Indian Register of Shipping or another certification agency recognized by the government.

Mercury Pollution

Mercury is a naturally occurring heavy metal that is found in various forms in the environment. It exists in three primary forms: elemental or metallic mercury, inorganic mercury compounds, and organic mercury compounds. It has detrimental effects on human health and the environment. Exposure to mercury may lead to toxic effects on the nervous, digestive and immune systems, and on lungs, kidneys, skin and eyes. It is important to note that no established safe threshold of exposure to mercury has been identified. Currently, there are no universally accepted diagnostic criteria for determining mercury overload.

Natural Sources of Mercury Pollution:

- Volcanic Activity: Volcanic eruptions release mercury into the atmosphere through volcanic gases and ash, contributing to natural sources of mercury pollution.
- Weathering of Rocks: Natural weathering processes of rocks and minerals containing mercury can lead to the release of mercury into the environment, including water bodies.

Anthropogenic Sources of Mercury Pollution:

- **Artisanal and Small-Scale Gold Mining:** Gold mining activities, particularly artisanal and small-scale mining operations, often involve the use of mercury to extract gold from ore. According to the UNEP's Global Mercury Assessment, 2018, it is the largest source of anthropogenic mercury pollution (37.7%).
- **Coal Combustion:** Burning coal for electricity generation and industrial processes is a significant anthropogenic source of mercury pollution. When coal containing mercury is burned, the mercury is released into the atmosphere as a gas or fine particles.
- **Industrial Processes:** Various industrial activities, such as chlor-alkali production, cement production, and waste incineration, can release mercury into the environment. Mercury is used in certain industrial processes and products, and improper management of mercury-containing waste can result in its release.
- **Waste Disposal:** Improper disposal of mercury-containing products, such as batteries, fluorescent lamps, and electronic devices, can contribute to mercury pollution. When these items end up in landfills or incinerators, mercury can be released into the environment.

Efforts to Control Mercury Pollution

Minamata Convention: It is a multilateral environmental agreement (effective from 2017) that addresses specific human activities which are contributing to widespread mercury pollution.

- **Aim:** to protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds.
- **Signatories:** 128, including India.

Bali Declaration on Combating Global Illegal Mercury Trafficking: It was launched by Indonesia at 4th Meeting of the Conference of the Parties phase two (COP4.2) of the Minamata Convention. It is non-legally binding. It aims to encourage international cooperation and coordination to combat illegal mercury trade.

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AIR POLLUTION

Air pollution refers to the presence of harmful substances or pollutants in the earth's atmosphere, which have negative effects on human health, wildlife, and the natural environment. These pollutants are either natural or man-made and take various forms, including gases, particulate matter, and biological molecules. The Air (Prevention and Control of Pollution) Act of 1981 defines 'air pollution' as **the presence of any dangerous pollutant that makes the air unbreathable.**

STATUS OF AIR POLLUTION

Global

According to data from the World Health Organization (WHO), globally, 99% of the population inhales air that contains high levels of pollutants and exceeds the recommended WHO guidelines. The populations of low- and middle-income countries are particularly affected by these high levels of air pollution.

India

Air pollution remains a significant environmental challenge in India. Many cities and towns across the country experience high levels of air pollution, primarily caused by industrialization, vehicular emissions, agricultural activities, and burning of fossil fuels.

- According to the **World Air Quality Report 2021** released by **IQ Air,** 63 Indian Cities are in 100 Most Polluted Places on Earth. Bhiwadi in Rajasthan ranked the most polluted city in the world, followed by Ghaziabad (Uttar Pradesh) at second position and Delhi at the 4th position.
- Research conducted **by Greenpeace India in 2022** concluded that the risks of air pollution are not evenly distributed, and the greatest proportion of Indians are exposed to PM 2.5.
- As per the report titled "Different Air Under One Sky" by Inequity Air Research, India has one of the worst air qualities with the greatest proportion of people exposed to PM2.5 concentrations, more than five times the annual average guideline by the World Health Organization.

CAUSES OF AIR POLLUTION

The primary cause of air pollution is the presence of harmful substances in the air. While most cases of air pollution are caused by human actions, such as industrial processes or transportation, some are also the result of natural phenomena.

Air pollution caused by natural events

Volcanic eruptions

Volcanic eruptions release ash, gases, and other particles into the air, which lead to poor air quality and health problems. The specific composition of these emissions depends on the type of volcano, the magnitude of the eruption, and the surrounding environmental conditions. Volcanic eruptions contribute to the air pollutions by the following ways:

- **Ash and particulate matter**: Volcanic eruptions release large amounts of ash and particulate matter into the air. These tiny particles travel long distances and have a significant impact on air quality, reducing visibility and contributing to respiratory problems.
- **Gases**: Volcanic eruptions release a range of gases, including sulphur dioxide, carbon dioxide, and nitrogen oxides. These gases react with other compounds in the atmosphere to form fine particulate matter, which have detrimental impacts on air quality and public health.
- **Acid rain**: Sulphur dioxide and other gases released during volcanic eruptions react with water vapor in the atmosphere to form acid rain.

Eruption of Mt Kilauea in Hawaii

Mt Kilauea Volcanic Eruption in Hawaii in 1986 had widespread international effects. The gas cloud moved quickly, creating a rapidly expanding mass of atmospheric pollution. Northeast trade winds diffused the gas cloud over much of the southwest region of the Hawaiian island. The dense hydrogen chloride and hydrogen sulphide cloud precipitated acidic rain over the entire island; A high diffusion of fog also occurred at the eruption of Kilauea. The residents exposed to fog developed various health issues like shortness of breath, coughing, rhinorrhea, sinus congestion, eye irritation, and bronchitis.

Dust storms

These are caused by strong winds that pick-up dust and soil particles from dry land surfaces, such as deserts, and carry them into the atmosphere. Dust storms contribute to the air pollutions by the following ways:

- **Particulate matter**: Dust storms release large amounts of particulate matter into the air. These tiny particles travel long distances and have a detrimental impact on air quality.
- **Allergens**: Dust storms can also carry allergens such as pollen, mold, and animal dander into the air, which cause allergic reactions in people with sensitivities.
- **Micro-organisms**: Dust storms also carry microorganisms such as bacteria and viruses, which cause respiratory infections and other illnesses.

Impact of dust storms

A report from the United Nations (UN) indicates that sand and dust storms expose over 500 million individuals in India and more than 80% of the total populations of Turkmenistan, Pakistan, Uzbekistan, Tajikistan, and Iran to medium and high levels of polluted air. Extreme drought conditions in parts of Western Australia, southeastern Turkey, Iran, and Afghanistan are expected to increase the risk of impacts from sand and dust storms in the 2030s.

Negative impact of dust storms

- **Impact on power plants:** The interference of dust storms with energy infrastructure can lead to power outages and negatively impact the transmission of electricity. For instances, In India, China, and Pakistan, energy losses of 1,584 gigawatt-hours (gWh), 679 gWh, and 555 gWh were observed, respectively.
- **Impact on freshwater sources:** Dust deposition hampers the Himalaya-Hindu Kush Mountain range and the Tibetan Plateau, which is often referred to as the 'third pole' since it is the source of fresh water for over 1.3 billion individuals in Asia.
- **Impact on melting of ice sheets:** Dust deposition on glaciers creates a warming effect, causing the ice to melt more quickly. These impacts affect food security, energy production, agriculture, water availability, and flood patterns.
- **Impact on farmlands:** Dust is known for its high salt content, which makes it harmful to plants. When crops are exposed to this type of dust, it lowers yield and cause a significant threat to the production of irrigated crops such as cotton.

Positive impact of dust storms

Increase in nutrient content: The deposition of dust can increase the nutrient content of the affected areas, which can benefit vegetation.

- **Impact on marine food webs:** Dust particles containing iron can enhance certain parts of the oceans, leading to an improvement in the balance of phytoplankton and influencing marine food webs.

Wildfires

Natural wildfires caused by lightning or other factors release a large amount of particulate matter, ash, and gases into the air, causing poor air quality and health problems. Wildfires contribute to the air pollutions by the following ways:

- **Smoke**: The smoke from wildfires contains a variety of pollutants, including particulate matter, carbon monoxide, nitrogen oxides, and volatile organic compounds. These pollutants are carried over long distances by wind, and can cause respiratory problems, eye irritation, and other health issues.
- **Ozone**: Wildfires also contribute to the formation of ground level ozone, a harmful air pollutant that cause respiratory problems and other health issues.
- **Carbon dioxide**: Wildfires release large amounts of carbon dioxide into the atmosphere, which contributes to global warming and climate change.
- **Regional impacts**: Wildfires have severe impacts on air quality in the regions where they occur, as well as on nearby communities. For example, in the western United States, wildfires have led to hazardous air quality levels in many cities and towns.

Air pollution caused by anthropogenic events

- **Vehicular emissions:** Harmful substances like carbon monoxide, nitrogen oxides, particulate matter, and volatile organic compounds are released into the air by cars, trucks, buses, and other motor vehicles. The major pollutants released as vehicle/fuel emissions are, carbon monoxide (CO), nitrogen oxides (NOx), photochemical oxidants, air toxics, namely benzene (C6H6), aldehydes, 1,3 butadiene (C4H6), lead (Pb), particulate matter (PM), hydrocarbon (HC), oxides of sulphur (SO2) and polycyclic aromatic hydrocarbons (PAHs).
  - The predominant pollutants in petrol- driven vehicles are hydrocarbons and carbon monoxide.
  - The predominant pollutants from the diesel-based vehicles are oxides of nitrogen and particulates.

Causes of high vehicular emissions in Urban India

- High vehicle density in Indian urban centers.
- Predominance of older vehicles
- Predominance of private vehicles especially cars and two-wheelers, owing to unsatisfactory public transport system, thereby causing higher idling emissions and traffic congestion.
- Absence of adequate land use planning in development of urban areas, thereby causing more vehicle travel and fuel consumption.
- Inadequate inspection & maintenance facilities.
- Adulteration of fuel & fuel products.
- Improper traffic management system & road conditions.
- High levels of pollution at traffic intersections.
- Absence of effective mass rapid transport system & intra-city railway networks.
- High population exodus to the urban centers.
- Increasing number of skyrocketing buildings in the urban areas causes stagnation of the vehicular emissions to the ground level and preventing its proper dispersion.

- **Industrial activities**, including factories and power plants, that emit large amounts of toxic chemicals and greenhouse gases into the atmosphere. According to the official data of the International Energy Agency, Industries contribute around 20% of global greenhouse gases that directly have an impact on air pollution.

Fly ash

It is a residual unburnt by-product produced from coal based thermal power plants during the combustion process.

Composition of Fly Ash

The composition of fly ash depends upon the type of coal that is used for combustion.

The residues that are discharged into the atmosphere is as fly ash contain:

- Arsenic
- Beryllium
- Silicon Oxides
- Ferric Oxides
- Aluminum Oxides
- Calcium Oxides
- Dioxins
- Unburnt Carbon elements.

Uses of Fly Ash

- Fly ash upon mixing with the soil increases the water holding capacity, resulting in higher crop yield.
- Used as soil conditioners in agriculture.
- Used in mine reclamation.
- Used for road construction.
- Fly ash exhibits good **pozzolanic properties**. Therefore, it is used for making concrete, brick and Portland cement.
- Used in embankment and other structural fillings.

Harmful Effects of Fly Ash

- Causes pollution of air and water.
- Upon deposition on the leaves of plants, it inhibits photosynthesis.
- Causes respiratory diseases.
- Affects the root development system of trees.

Initiatives

- In 2021, **National Thermal Power Corporation** (NTPC) issued an Expression of Interest (EOI) for the sale of fly ash.
- **NTPC** has partnered with cement manufacturers across the country to supply fly ash.
- The **Pradhan Mantri Awas Yojana** (**Urban**) is promoting the use of innovative and environmentally friendly construction technologies, such as fly ash bricks.
- Some state governments have adopted their own fly ash utilization policies, with Maharashtra being the first to do so.
- The government has launched a web portal and mobile application called "**ASHTRACK**" for monitoring the generation and utilization of fly ash.
- **Fly Ash Management and Utilization Mission**: The NGT directed the constitution of the mission. It aims to coordinate and monitor issues relating to the handling and disposal of fly ash and associated issues.

- **Agricultural practices**, such as the use of pesticides and fertilizers, release harmful chemicals into the air. Further, stubble burning is a major cause of air pollution.

Stubble burning

Stubble burning, also known as parali, is a technique used to clear paddy crop residue from fields before planting wheat during the period between the last week of September and November. This timeframe typically coincides with the end of the southwest monsoon season.

Effects of stubble burning:

- **Air pollution:** Stubble burning emits toxic pollutants, including methane, carbon monoxide, volatile organic compounds, and carcinogenic polycyclic aromatic hydrocarbons, which have negative impacts on human health.

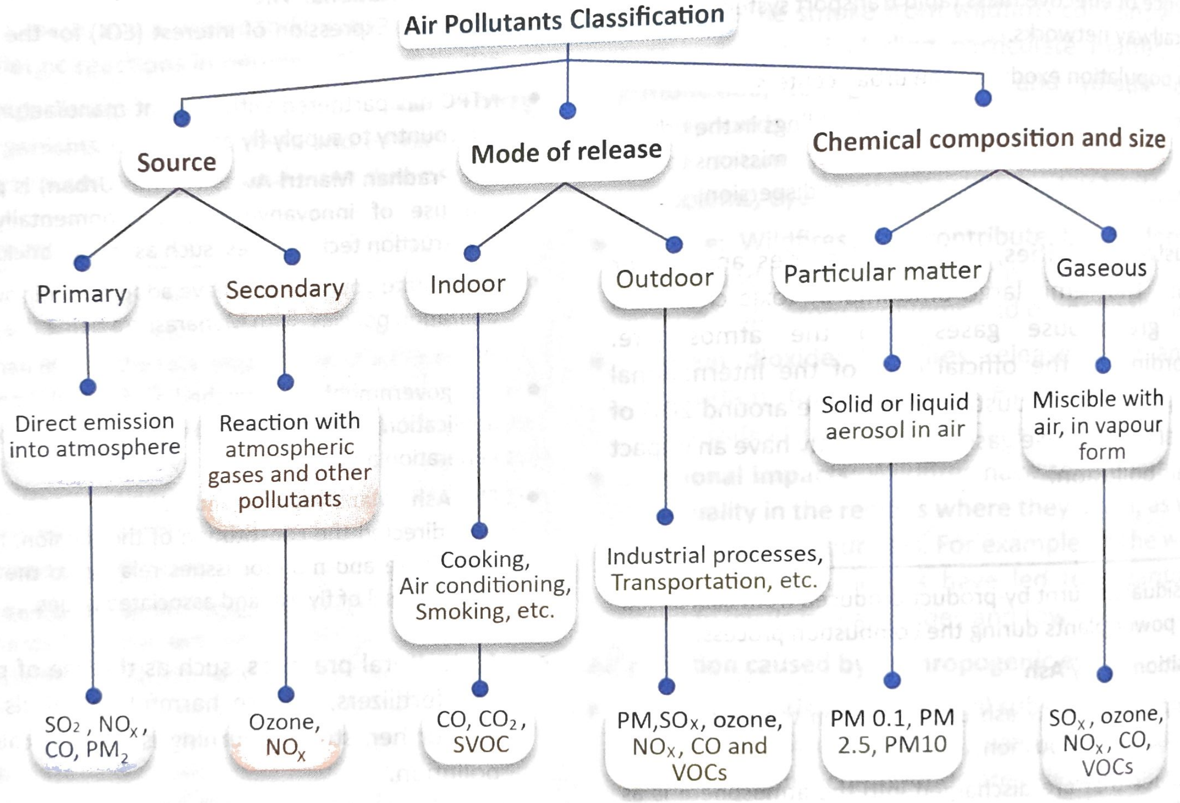
- **Soil fertility:** The act of burning husk on the ground lead to the destruction of soil nutrients, resulting in a decrease in soil fertility.
- **Heat penetration:** Stubble burning generates heat that penetrate the soil, resulting in the loss of moisture and beneficial microbes.

- **Waste management practices**, such as landfills and open burning of waste emits harmful substances into the air.
- **Energy production**, particularly the use of fossil fuels, which releases large amounts of carbon dioxide and other pollutants into the air.

Air Pollutants

The **Air (Prevention and Control of Pollution) Act of 1981**, defines an '**air pollutant**' as any solid liquid or gaseous substance which may cause harm or damage the environment, humans, plants, animals or even damage property. A pollutant in the air might be a solid particle, a liquid droplet, or a gas, and it is recognized by this name because it poses a threat to human health and the environment. They may be primary or secondary pollutants, and can be either naturally occurring or artificially produced.

Classification of air pollutants


Air Pollutants Classification
Source
Mode of release
Chemical composition and size
Primary
Secondary
Indoor
Outdoor
Particular matter
Gaseous
Direct emission into atmosphere
Reaction with atmospheric gases and other pollutants
Cooking, Air conditioning, Smoking, etc.
Industrial processes, Transportation, etc.
Solid or liquid aerosol in air
Miscible with air, in vapour form
SO_2 , NO_X , CO, PM_2
Ozone, NO_X
CO, CO_2 , SVOC
PM,SO_X, ozone, NO_X, CO and VOCs
PM 0.1, PM 2.5, PM10
SO_X , ozone, NO_X , CO, VOCs

Air pollutants can be classified in various ways, including by origin, state of matter, and source.

- **According to origin:** Pollutants are divided into primary and secondary pollutants.
  - **Primary pollutants**: These are pollutants which are directly released into the atmosphere from identifiable sources either through natural events or human activities. For example, smoke, dust, oxides of nitrogen and sulphur, hydrocarbons, particulate matter etc.
  - **Secondary Pollutants**: These are pollutants formed through chemical reactions between primary pollutants and atmospheric constituents. For example, Sulphur trioxide, ozone, ketones, sulphuric acid, nitric acid, carbonic acid etc.
- **According to their existence in nature:** Pollutants are divided into quantitative and qualitative pollutants.
  - **Quantitative pollutants**: These are substances whose concentration in the environment has exceeded the safe threshold. Examples include ozone, sulfur dioxide, nitrogen dioxide, and particulate matter.

- **Qualitative pollutants:** These are chemicals that are not naturally occurring in the environment. They are introduced by human activities and contribute to air pollution. Examples include chemicals such as chlorofluorocarbons (CFCs), polychlorinated biphenyls (PCBs) etc.
- **According to state of matter:** Air pollutants can be categorized as gaseous or particulate.
  - **Gaseous pollutants:** These exist in a gaseous state at normal temperature and pressure
  - **Particulate pollutants:** These are suspended droplets, solid particles, or mixtures of the two.
- **According to sources:** Air pollutants can originate from natural and anthropogenic sources.
  - **Natural sources** include volcanic eruptions, dust storms, and forest fires.
  - **Anthropogenic sources** include industrial activities, transportation, and waste treatment plants

Major Air pollutants

Air Pollutant	Description	Source	Effect on Health and Environment
Particulate Matter (PM)	**PM2.5:** refers to tiny particles or droplets in the air that are 2.5 micrometers in diameter or smaller. **PM10:** refers to airborne particles or droplets that are 10 micrometers in diameter or smaller. **Composition:** • Sulphate • Nitrate • Ammonia • Sodium chloride • Black carbon • Dust and soot	• Pollen • Sea spray • Windblown dust from: ◆ Construction ◆ Agriculture ◆ Transport ◆ Mining ◆ Soil erosion	PM is capable of penetrating deep into the lung and enter the bloodstream causing • Cardiovascular disease, • Cerebrovascular stroke • Respiratory impacts.
Nitrogen dioxide	Nitrogen dioxide (NO2) is a reddish-brown gas that is soluble in water, and a strong oxidant. NO2 is a major source of ozone	• Combustion of fossil fuels • Combustion of crop residue • Combustion of woods • Vehicular emissions • Industrial processes • Chemical productions • Wood burn fuels	• Coughing • Wheezing • Shortness of breath • Strokes and heart attacks (cardiovascular problems) • Reduced lung function
Ozone	When NOx and VOCs are released into the atmosphere, they can react in the presence of sunlight to form ground-level ozone. This process is called photochemical smog formation. The chemical reactions that produce ground-level ozone involve a number of intermediate compounds, including peroxyacyl nitrates (PANs) and other organic compounds.	• Vehicular emissions • Factories • Paints, solvents and cleaning agents emit volatile organic compounds (VOCs)	• Damages the DNA • Impaired cellular function • Shortness of breath • Asthma Due to the low water solubility of ozone, inhaled ozone has the capacity to deeply penetrate into the lungs.

Air Pollutant	Description	Source	Effect on Health and Environment
Carbon monoxide (CO)	Carbon monoxide (CO) is a colorless, odorless gas that is produced by the incomplete combustion of fossil fuels and biomass. It is a common air pollutant, and exposure to high levels of carbon monoxide can be harmful to human health.	• Vehicular emission • Home heating (natural gas, fuels) • Industrial processes • Wildfires • Tobacco smoke • Power plants	• Infants • Pregnant women • Heart disease • Respiratory diseases Upon entering the bloodstream, carbon monoxide inhibits the body's ability to carry oxygen to organs and tissues. As such, extremely high concentrations can cause death.
Sulphur dioxide (SO2)	Sulphur dioxide (SO2) is a colorless gas that is readily soluble in water. Sulphur dioxide is a harmful gas. The annual standard of SO2 is 0.03 ppm.	• Residential heating • Transportations • Industrial processes • Power plants	• Respiratory irritation • Bronchitis • Bronchospasm
Lead	Lead is a heavy metal used in different industrial plants and emitted from some petrol motor engines, batteries, radiators, waste incinerators and waste waters.	• Lead based paint • Consumer products • Industrial emissions • Gasoline • Batteries	• Behavior and learning problems • Lower IQ • Hyperactivity • Slowed growth • Hearing problems • Anemia • Anemia
Benzene	Benzene is a colorless and highly flammable liquid with a sweet odor. It is an organic chemical compound. Benzene is widely used in the manufacturing of many products, including plastics, rubber, synthetic fibers, detergents, drugs, and pesticides. It is also used as a solvent in various industries, including paint, printing, and leather processing.	• Motor vehicle exhaust • Industrial processes • Cigarette smoke • Glues • Adhesives • Cleaning products	• Immune system damage • Reproductive problems • Cancer • Leukemia • Carcinogen
Ammonia	Ammonia is a colorless gas with a pungent smell. It is a basic compound and can be produced through natural processes, such as decomposition of organic matter, or through industrial processes, such as the Haber-Bosch process for producing fertilizer.	• Fertilizer industry • Treatment of wastewater and sewage • Animal husbandry facilities • Production of synthetic fibers	• Chronic bronchitis • Respiratory problems • Toxic fumes from industrial processes. • Shortness of breath
Ethylene	Ethylene is a colorless gas that is commonly used in industry for the production of various plastics, resins, and synthetic fibers.	• Industrial processes • Burning of natural gas • Tobacco smoke • Combustion processes	• Respiratory problems • Skin irritation • Neurological effects • Reproductive and developmental effects.

Air Pollutant	Description	Source	Effect on Health and Environment
Asbestos	Asbestos is a naturally occurring mineral that was commonly used in construction and manufacturing due to its heat resistance and durability. Asbestos fibers are very small and can easily become airborne The use of asbestos has been banned or heavily restricted in many countries around the world due to its health hazards, but it is still used in some countries, especially in the developing world.	• Rocks and soil • Building materials • Insulators • Cement • Industries • Automotive parts	• Lung cancer • Mesothelioma (a cancer of the lining of the lungs and other organs) • Asbestosis (a chronic lung condition)
Radon	Radon is a naturally occurring radioactive gas that is produced by the decay of uranium and thorium in soil, rocks, and water. It is odorless, colorless, and tasteless, which makes it difficult to detect without specialized equipment.	• Found in areas with high levels of naturally occurring uranium and thorium	• Lung cancer • Damage to lung tissues

Styrene Gas

In May 2020, a styrene gas leak from the LG Polymers chemical factory in Visakhapatnam resulted in several deaths.

- **Characteristics of Styrene:** It is an organic compound and is a derivative of Benzene. It is stored in liquid state and easily evaporates
- **Usage:** Styrene is used as the prime raw material for the manufacturing of polystyrene.
- **Health effects of styrene gas:** The gas affects the central nervous system and may cause leukemia in long terms.

IMPACT OF AIR POLLUTION

Air pollution has wide-ranging consequences, impacting various facets of life. It harms human health, causes acid rain, and damages forests, wildlife, and agriculture. Moreover, greenhouse gas pollution, which is responsible for climate change, affects the entire planet.

Effect of air pollution on human health

The World Health Organization reported that India's air pollution, reduces the life expectancy of the majority of Indians by over 3 years. Some of the negative impacts of air pollution on human health include:

- **Respiratory problems**: Air pollution cause a variety of respiratory problems, including asthma, bronchitis, and emphysema. It also aggravates existing respiratory conditions and lead to lung damage.
- **Cardiovascular disease**: Exposure to air pollution increase the risk of cardiovascular disease, including heart attack and stroke.
- **Cancer**: Air pollution has been linked to several types of cancer, including lung cancer, bladder cancer, and breast cancer.
- **Neurological problems**: Studies have shown that air pollution have negative impacts on cognitive function and may increase the risk of developing neurological diseases like Alzheimer's disease.
- **Reproductive problems**: Air pollution has been linked to reproductive problems, including low birth weight and preterm birth.
- **Skin problems**: Exposure to air pollution leads to skin irritation, allergies, and other skin problems.

Effects of air pollution on animals and plants

Air pollution have significant impacts on animals and plants as well. Some of the effects of air pollution on animals and plants include:

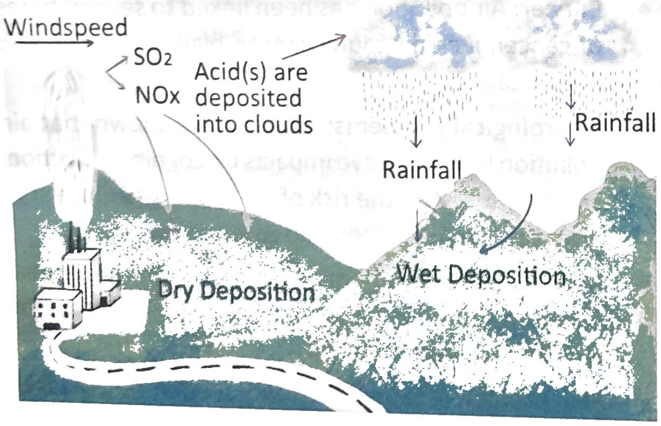
- **Respiratory problems**: Just like humans, animals suffer from respiratory problems due to air pollution. Birds and mammals are particularly vulnerable to air pollution, which cause respiratory distress, coughing, and other respiratory issues.

- **Changes in behavior and reproduction**: Air pollution disrupt the reproductive behavior of animals, as well as their migration patterns and feeding habits.
- **Damage to crops and forests**: Air pollution damage crops and forests, reducing yields and impacting plant growth. It also contributes to the death of trees and other plants.
- **Water pollution**: Some air pollutants deposit into water sources, which negatively impact aquatic animals and plants.
- **Loss of biodiversity**: Air pollution leads to a decline in biodiversity by damaging habitats and reducing the availability of food and other resources for animals and plants.

Acid Rain

Acid rain (acid deposition) refers to any form of precipitation (rain, snow, hail, or even acidic dust) that contains acidic substances, such as sulfuric or nitric acid. It falls to the ground in wet or dry forms. Normal rain has a pH of about: 5.6, while acid rain usually has a pH between 4.2 and 4.4.

Formation of Acid Rain



Acid Rain

Acid rain is caused by the emission of sulfur dioxide (SO2) and nitrogen oxides (NOX) into the atmosphere. Pollutants react with water, oxygen, and other chemicals to form sulfuric and nitric acids. These acids can subsequently fall to the ground in different forms, including rain, snow, hail, or dust.

Effects of acid rain

- **Aquatic Ecosystem:** Acid rain largely affects aquatic ecosystems, such as lakes, streams, and marshes, posing a threat to aquatic life. Certain species of plants and animals can withstand moderately acidic waters and aluminium. However, species which are acid-sensitive die as the pH levels drop.
- **Terrestrial Plants and Trees:** Acid rain causes aluminium to leach from the soil, which can be harmful to both plants and animals. Additionally, acid rain depletes the soil of necessary minerals and nutrients that trees need to grow.
    - In high altitude areas, acidic fog and clouds can strip nutrients from the foliage of trees. This causes brown or dead leaves and needles, which hinder their ability to absorb sunlight, making them vulnerable to freezing temperatures.
- **Nitrogen Pollution:** Acid rain not only contains high acidity levels but also nitrogen, which can be damaging to some ecosystems. Excessive nitrogen pollution, in combination with agricultural and wastewater discharge, contributes to the decline of fish and shellfish populations in coastal waters, largely due to nitrogen produced by human activities being carried into the atmosphere
- **Human Health:** When acid rain takes the form of inhalable fog, it can cause health problems including eye irritation and asthma.
- **On Physical Structures:** Acid deposits damage physical structures such as limestone buildings and cars.

Episodic Acidification

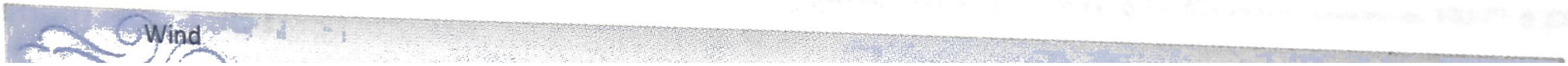
During events such as heavy rainfall or melting snow, acid rain can cause temporary spikes in acidity levels, known as episodic acidification. Consequently, there is an accumulation of acidic deposition that surpasses the soil's capacity for neutralization The temporary increase in acidity can cause harm to various organisms or species in the ecosystem and cause short-term stress to the system.

Smog

The word smog is formed from two words that are Smoke and Fog. It is a type of air pollution, which is caused by the burning of coal, petroleum, natural gas, etc. It consists of various pollutants such as soot, sulfur dioxide, nitrogen dioxide, etc.

On the basis of the nature of the formation, Smog is divided into two types: Photochemical Smog and Sulfurous Smog

Photochemical Smog



It is also known as brown smog or London smog (first time formed in London). It is formed when sunlight reacts with nitrogen oxides and volatile organic compounds (VOCs) emitted by vehicles and industrial processes. This reaction creates a mixture of chemicals, including ozone, aldehydes, and peroxyacetyl nitrate (PAN).

Chemical Reactions Involved:

- Nitrogen dioxide ($NO2$) reacts with sunlight to form nitrogen oxide (NO) and an oxygen molecule ($O2$):

  $\text{NO2 + sunlight} \rightarrow \text{NO + O2}$

- Nitrogen oxide (NO) reacts with oxygen ($O2$) to form nitrogen dioxide ($NO2$):

  $\text{NO + O2} \rightarrow \text{NO2}$

- Volatile organic compounds (VOCs) such as hydrocarbons and aldehydes react with nitrogen oxides (NOx) in the presence of sunlight to form ozone ($O3$) and other secondary pollutants such as peroxyacetyl nitrate (PAN):

  $\text{VOCs + NOx + sunlight} \rightarrow \text{O3 + PAN + other secondary pollutants}$

Sulfurous Smog

It is also known as Grey Smog or Los Angeles smog (first time formed). It is formed when sulfur dioxide and other sulfur compounds after releasing into the atmosphere from industries and vehicles react with water and oxygen and lead to the formation of Sulfuric acid.

Chemical Reactions Involved

- Sulfur dioxide ($SO2$) reacts with oxygen ($O2$) to form sulfur trioxide ($SO3$):

  $\text{2SO2 + O2} \rightarrow \text{2SO3}$

- Sulfur trioxide ($SO3$) reacts with water ($H2O$) to form sulfuric acid ($H2SO4$):

  $\text{SO3 + H2O} \rightarrow \text{H2SO4}$

- Sulfuric acid ($H2SO4$) can then react with other pollutants in the atmosphere to form particulate matter:

  $\text{H2SO4 + other pollutants} \rightarrow \text{particulate matter}$

Effects of Smog

Impacts on	Effects
Humans	• Respiratory problems such as coughing, wheezing, shortness of breath, and asthma attacks. • Eye irritation, including itching, burning, and watering. • Headache, dizziness, and fatigue. • Increased risk of heart disease and stroke. • Increased risk of lung cancer.
Plants	• Reduced photosynthesis and growth due to decreased sunlight. • Damage to leaves stems, and roots. • Increased susceptibility to pests and disease. • Changes in plant physiology, such as altered nutrient and water uptake.
Animals	• Reduced activity levels and decreased appetite. • Changes in behavior, such as altered migration patterns and mating habits. • Increased susceptibility to disease.
Environment	• Reduced visibility due to the presence of haze. • Acid rain, due to the release of sulfur dioxide and nitrogen oxides. • Damage to buildings, monuments, and other structures. • Reduced water quality due to the deposition of pollutants in water bodies. • Disruption of ecosystems, including changes in the abundance and distribution of species.

Vog

Vog stands for "Volcanic Smog". It is a type of air pollution that is created when sulfur dioxide ($SO2$), carbon dioxide ($CO2$), and other gases and particles are released into the air by an active volcano. It is very similar to Smog and Haze in terms of appearance and effects. The major distinguishing factor is that it is released from volcanos and can have distinct chemical and physical properties from atmospheric pollution.

Haze

Haze is an atmospheric phenomenon, which is characterized by the presence of fine dust, smoke, and other dry particles that obscure the clarity of the air, making distant objects appear blurry or hazy. It is typically caused by human activities, such as industrialization, transportation, and agriculture, as well as natural events like forest fires and volcanic eruptions.

Effects of Haze

- It lowers visibility in Urban areas.
- Can increase the risk of heart disease, stroke, and lung cancer.
- Can reduce the overall quality of life, including physical health, mental well-being, and social and economic factors.
- Can damage leaves and reduce plant vitality, making them more susceptible to diseases and pests.
- Can alter plant diversity and disrupt ecosystems, leading to negative impacts on wildlife and habitats.
- Can contribute to acid rain, which can damage soil, water, and other natural resources.
- Can impact tourism and recreation, as haze can diminish the natural beauty of landscapes.

Comparison between Smog and Haze

	Smog	Haze
Cause	Interaction of pollutants in the air	Natural and human-made sources
Composition	Pollutants such as sulfur dioxide, nitrogen oxides, and ozone	Fine particles such as dust and smoke
Appearance	Thick, a brownish-grey haze that hangs over cities	Lighter, less dense, and more translucent
Health Impact	Can cause severe respiratory problems, eye irritation, headaches, and other health issues	Can cause respiratory problems, eye irritation, and other health issues, but effects are generally less severe

INITIATIVES TO COMBAT AIR POLLUTION IN INDIA

The Air (Prevention and Control of Pollution) Act, 1981

In 1981, the Parliament of India passed the Air (Prevention and Control of Pollution) Act, commonly referred to as the Air Act. It aims at the prevention, control, and abatement of air pollution.

- **Key Features:**
  - Empowers the central and state governments to take measures to prevent and control air pollution.
  - Provides for establishment of standards for emissions from industrial and vehicular sources, and sets penalties for non-compliance with these standards.
  - Control of emissions from new and existing sources and the development of strategies to mitigate air pollution.
  - Implementation of air pollution control programs, monitoring of air quality,
  - Issuance of directions to industries and local bodies for the prevention and control of air pollution.

National Clean Air Programme (NCAP)

Launched in 2019, by the Ministry of Environment, Forest and Climate Change (MoEFCC), it is a first-of-a-kind national framework for air quality management with a time bound reduction target.

- **Target:** The target is to reduce PM10 by 40% with 2017 as the base year by 2026 and PM2.5 by 20% with 2017 as the base year by 2026.
- **Coverage:** Under NCAP, cities which are exceeding the National Ambient Air Quality Standards (NAAQS) for 5 consecutive years are identified as non-Attainment cities by CPCB. It covers 131 non-attainment cities that are identified by the Central Pollution Control Board.

Prana Portal

PRANA" – Portal for Regulation of Air-pollution in non-Attainment cities, is a portal for monitoring of implementation of National Clean Air Programme (NCAP). It helps in tracking physical and financial status of city air action plan implementation. It also disseminates information on air quality management efforts under NCAP to public.

National Ambient Air Quality Standards (NAAQS)

NAAQS are standards established by the Central Pollution Control Board (CPCB) to regulate the levels of air pollutants. The standards are set to ensure the protection of public health and the environment from harmful effects of air pollution.

- **Objectives:** The major objectives of NAAQS are:
    - To indicate the levels of air quality necessary with an adequate margin of safety to protect the public health, vegetation and property.
    - To assist in establishing priorities for abatement and control of pollutant level.
    - To provide a uniform yardstick for assessing air quality at national level.
    - To indicate the need and extent of monitoring programme
- **List of pollutants under NAAQS are:**
    - PM10
    - PM2.5
    - Sulphur Dioxide
    - Nitrogen Dioxide
    - Carbon Monoxide
    - Ammonia
    - Ozone
    - Lead
    - Benzene
    - Benzo-Pyrene
    - Arsenic
    - Nickel

National Air Monitoring Programme (NAMP)

Central Pollution Control Board (CPCB) initiated National Ambient Air Quality Monitoring (NAAQM) programme in the year 1984. It was subsequently renamed as National Air Monitoring Programme. Under N.A.M.P., four air pollutants viz., Sulphur Dioxide (SO2), Oxides of Nitrogen as NO2 and Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM/PM10) are monitored at different locations.

Air Quality Index (AQI)

Launched by the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, in 2015, it serves as a useful tool to monitor and convey the air quality status to the public in a simplified manner. It is implemented by the CPCB.

- There is a total of six AQI categories, which include Good, Satisfactory, moderately polluted, Poor, Very Poor, and Severe. The AQI ranges from 0 to 500, with higher values indicating higher pollution levels.
- **Pollutants covered:** The AQ sub-index and health breakpoints have been developed for **eight different pollutants** for which the National Ambient Air Quality Standards prescribe short-term limits of up to 24 hours. The pollutants covered are:
    - PM10
    - PM2.5
    - Nitrogen oxide (NO2)
    - Sulphur dioxide (SO2)
    - Carbon-monoxide (CO)
    - Ozone (O3)
    - Ammonia (NH3)
    - Lead (Pb)

Air Quality Index

Color	Range	Category	Meaning
Green	0-50	Good	Air quality is at a satisfactory level. Risk of air pollution is minimal or non-existent.
Yellow	51-100	Satisfactory	Air quality is acceptable. Possibility of pollutants which could cause **minor** health issues.
Orange	101-200	Moderate	Air quality is acceptable. Possibility of pollutants which could cause **moderate** health issues.
Red	201-300	Poor	Air quality has reached a level where members of vulnerable groups experience more severe consequences.
Violet	301-400	Very Poor	Health warning showing emergency conditions, and the entire population is likely to be impacted.
Maroon	401-500	Severe	Air quality has reached a critical level. Health alert is issued as everyone may experience severe health effects.

System of Air Quality and Weather Forecasting (SAFAR) Portal

SAFAR is a national program implemented to assess the air quality of a metropolitan city by measuring both the general pollution level and the air quality specific to each location within the city.

- **Objective:** The major objectives of SAFAR are:
    - To monitor various weather parameters such as temperature, rainfall, humidity, wind speed, wind direction, UV radiation, and solar radiation.
    - To raise awareness among the public about the air quality in their city.
    - To assist policy-makers in devising mitigation strategies while taking into consideration the economic progress of the nation.
- **Pollutants monitored**
    - PM2.5
    - PM10
    - Ozone
    - Carbon Monoxide (CO)
    - Nitrogen Oxides (NOx)
    - Sulphur Dioxide (SO2)
    - Benzene
    - Toluene
    - Xylene
    - Mercury

Categorization of Industries

CPCB has classified different industries according to their pollution levels into Red, Orange, Green, and White.

Category	Pollution Level	Example
Red	Pollution Index score of 60 and above	Thermal power plants, pharmaceuticals, fertilizers, Oil refineries, etc.
Orange	Pollution Index score of 41 to 59	Textiles, dyes, and dye intermediates, sugar, distilleries, etc.
Green	Pollution Index score of 21 to 40	Software development, IT-enabled services, food processing, packaging, etc.
White	Pollution Index score inclusive & up to 20	Small scale industries, cottage industries, industries in residential areas, solar power plants, wind power plants, etc.

Green Crackers

These are crackers that produce lower levels of air and noise pollution when compared to conventional firecrackers. Green crackers are estimated to cause 30 per cent less air pollution as compared to traditional ones. The National Green Tribunal (NGT) permits the use of green crackers only in cities and towns with moderate or poor air quality.

In 2018, these crackers were first launched by the Council for Scientific and Industrial Research (CSIR) oversaw along with National Environmental and Engineering Research Institute (NEERI). At present, three brands of green crackers are available for purchase:

- **SWAS (Safe Water Releaser):** Instead of using sulphur or potassium nitrate, these crackers emit water vapor, which avoids the release of harmful pollutants. By incorporating diluents, they can also reduce particulate matter (PM) emissions by up to 30%.
- **STAR (Safe Thermite Cracker):** Similar to SWAS, STAR crackers are also free of sulphur and potassium nitrate. In addition to reducing particulate dust emissions, they also produce lower levels of sound intensity.
- **SAFAL (Safe Minimal Aluminum):** By replacing aluminum with magnesium, the product generates lower amounts of pollutants.

Pradhan Mantri Ujjwala Yojana

Launched in 2016, the scheme addresses the issue of indoor air pollution. It aims to make clean cooking fuel such as LPG available to the rural and deprived households which were otherwise using traditional cooking fuels such as firewood, coal, cow-dung cakes etc. It is implemented by Ministry of Petroleum and Natural Gas.

- Under the scheme, deposit-free LPG connection is given to the eligible household with financial assistance of Rs 1,600 per connection. Free of cost first LPG refill and gas stove is provided for the first time by public sector Oil Marketing Companies (OMCs).
- The initial target was to provide LPG connections to Five crore women members of BPL households. Subsequently, the scheme was expanded and the target was revised to Eight crore LPG connections

- **Ujjwala 2.0**: It eliminates the struggle of migrant workers to obtain address proof documents for obtaining gas connections. Under the scheme, migrant workers can obtain a gas connection by submitting a self-declaration of their residential address.

Initiatives to Address Vehicular Emissions

BS Norms

Bharat Stage (BS) emission standards are a set of regulations established by the government of India to control the release of air pollutants from internal combustion engines and spark-ignition engines, including motor vehicles. The standards have been progressively updated to reduce emissions and improve air quality

The Central Government has made it mandatory that all vehicle manufacturers, both two-wheelers and four-wheelers, must manufacture, sell and register only BS-VI engines from 1st April 2020.

Difference between BS IV and BS VI

Criteria	BS-IV	BS-VI
NO2 emissions limit	80mg/km	60mg/km
PM emissions limit (petrol vehicles)	N/A	4.5mg/km
NOx emissions limit (diesel vehicles)	250mg/km	80mg/km
Sulphur content in fuel	50ppm	10ppm
Selective Catalytic Reduction (SCR) and Diesel Particulate Filter (DPF)	Not included	Included
Onboard Diagnostic (OD)	Not included	Included

Faster Adoption and Manufacturing of Electric Vehicles (FAME)

FAME India is a component of the National Electric Mobility Mission Plan. It was launched by the Department of Heavy Industry, since 2015. It aims to facilitate the sustainable development of electric and hybrid vehicle technology. It provides subsidy benefits to vehicles in various segments, including two-wheelers, three-wheelers, electric and hybrid cars, and electric buses. FAME focuses on 4 areas viz. Technology development, Demand Creation, Pilot Projects and Charging Infrastructure.

- **FAME-II:** It is a 3-year subsidy programme. It aims at supporting the electrification of public and shared transportation and establish charging infrastructures on major highways connecting major city clusters.

Other Measures

- **Public transport:** The government has enhanced the network of metro rails for public transport and more cities are being provided with metro facilities.
- **Expressways and Highways:** The government has developed Expressway and Highways to reduce the fuel consumption and pollution.
- **Cleaner fuels:** Cleaner/alternate fuels like CNG, LPG, ethanol blending in petrol have been introduced.

Case Study: Air Pollution in Delhi

In recent years, Delhi has consistently maintained its position as one of the most polluted capital cities in the world. The severity of air pollution can be understood by the comparison made by Berkeley Earth Science Research Group, which stated that breathing in Delhi's air during the month of November is equivalent to smoking 45-50 cigarettes in a single day.

Factors Responsible for Delhi's High Air Pollution

- **Stubble Burning:** Delhi is surrounded by agricultural dependent states like Punjab, Haryana, and Uttar Pradesh (western part). The stubble burning in these states, especially before the Rabi season causes a significant increase in the air pollution level.
- **North-Westerly Wind:** The Winds blowing from the North-West of India bring all the polluting particles along with them to Delhi.
- **Temperature Inversion:** Temperature inversion is a weather phenomenon that occurs when the temperature of the air near the ground is colder than the temperature of the air at higher altitudes. During the winter months, cool air settles near the ground, trapping pollutants and preventing them from dispersing into the atmosphere.
- **Firecrackers bursting:** During the Diwali season, Delhi experiences the bursting of firecrackers which releases various toxic gases such as sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), and particulate matter (PM).
- **Lack of Green Spaces:** According to MoEFCC, Delhi has a lower Green Space as compared to Mumbai and Chennai, which leads to an increase in pollutants in the air.

- **Landlocked position:** A significant difference between Delhi and other metropolitan cities like Mumbai, Kolkata, and Chennai is that Delhi lacks the positive impact of coastal areas in reducing pollution levels, including:
    - The coastal location provides natural ventilation and disperses pollutants into the atmosphere.
    - The sea breeze carries pollutants away from the city and on the other hand, brings fresh air to the city.

Initiatives Taken

- **Graded Response Action Plan (GRAP):** Introduced in 2017, GRAP is a holistic and Air Quality Index-based program that is designed to curb the air pollution level in Delhi NCR. The GRAP was developed in compliance with the Supreme Court's order in the case of M. C. Mehta vs. Union of India (2016) regarding air quality.
    - Until 2020, the Environment Pollution (Prevention & Control) Authority (EPCA), appointed by the Supreme Court, was responsible for directing the implementation of measures under the Graded Response Action Plan (GRAP) in various states.
    - In 2020, the EPCA was dissolved and replaced by the Commission for Air Quality Management (CAQM), which is a statutory mechanism tasked with coordinating and overseeing efforts to improve air quality in Delhi, Punjab, Haryana, Rajasthan, and Uttar Pradesh.

Categories of GRAP

Category	Pollution Level	Steps Taken
Moderate to poor	PM2.5 concentration between 61-120 µg/m3 or PM10 concentration between 101-350 µg/m3.	• Education and Awareness through social media and mobile Apps among the common people. • Strict vigilance over thermal power plants. • Mechanized sweeping • Strict ban on Firecrackers.
Very Poor	PM2.5 concentration between 121-250 µg/m3. or PM10 concentration between 351-430 µg/m3.	• Stop the use of diesel generator sets. • Enhance parking fee by 3-4 times. • Increase bus and metro services. • Stop the use of coal/firewood in hotels and open eateries. • Advise people with respiratory and cardiac patients to avoid polluted areas.
Severe	PM 2.5 concentration over 250 µg/m3. or PM10 concentration over 430 µg/m3.	• Close brick kilns, hot mix plants, and stone crushers. • Increase the frequency of mechanized sweeping. • Sprinkling of water on roads. • Encourage public transport.
Severe+ or Emergency	PM 2.5 concentration over 300 µg/m3 or PM10 concentration over 500 µg/m3. for 48+ hours	• Stop entry of truck traffic into Delhi. • Stop construction activities. • Introduce odd and even scheme for private vehicles. • Taskforce to decide any additional steps.

- **Other Measures**
    - Ban on use of pet coke and furnace oil in Delhi NCR
    - Operationalization of Eastern Peripheral Expressway & Western Peripheral Expressway to divert non destined traffic from Delhi.
    - Ban on 10-year-old diesel vehicles and 15-year-old vehicles in Delhi NCR.
    - Imposition of Environment protection charges (EPC) on diesel vehicles with engine capacity of 2000cc and above in Delhi NCR.

Current Status: With the efficient implementation of the GRAP, the number of severe air quality days in Delhi reduced significantly in 2022-from 26 in 2016 to six in 2022.

Gothenburg Protocol/Multi-effect Protocol

- **Background:** It was signed in 1999, and entered into force in 2005. It is part of the Convention on Long-Range Transboundary Air Pollution.
- **Aim:** It aims to reduce acidification, eutrophication and ground-level ozone. It sets limits on air pollutants including sulphur dioxide, nitrogen oxide, ammonia and volatile organic compounds that are hazardous to human health and the environment.

Convention on Long-Range Transboundary Air Pollution: It aims to protect the human environment against air pollution and to gradually reduce and prevent air pollution, including long-range transboundary air pollution. It is implemented by the European Monitoring and Evaluation Programme (EMEP), directed by the United Nations Economic Commission for Europe (UNECE). India is not a member of the Convention.

APPLICATION OF TECHNOLOGY TO CURB AIR POLLUTION

In Industries

There are several technological tools that are used in industries to control air pollution, including

- **Scrubbers:** These are devices that use liquid solutions to remove pollutants from industrial emissions before they are released into the atmosphere. There are several types of scrubbers, including wet scrubbers, dry scrubbers, and spray scrubbers.
    - **Working:** The liquid solution is sprayed into the emission stream, where it reacts with the pollutants and captures them. The cleaned gas is then released into the atmosphere, while the captured pollutants are disposed of properly.
- **Electrostatic precipitators:** These are devices that use an electrical charge to control air pollution.
    - **Working:** The dirty air passes through a series of plates that are charged with an electric current. The charged plates attract and capture the particles, which are then removed and disposed of. The clean air is then released into the atmosphere
- **Catalytic converters** These use a chemical reaction to regulate pollution from industries.
    - **Working:** Catalytic converters use a chemical reaction to convert harmful pollutants into less harmful compounds. They are typically made of a ceramic or metal honeycomb structure coated with a catalyst such as platinum, palladium, or rhodium. As the exhaust gases pass through the honeycomb, the catalyst causes a chemical reaction that breaks down harmful pollutants into less harmful ones before being released into the atmosphere.
- **Filtration systems:** Filtration systems filters the pollutants from the air by using different filters such as bag filters, cartridge filters, and HEPA filters.
    - **Working:** It works in simple form as we filter things in our homes. The emissions pass through a series of filters, which trap the particles and allow the clean air to pass through. The captured particles are then disposed of properly, while the clean air is released into the atmosphere.
- **Inertial collectors:** They use centrifugal force to control air pollution.
    - **Working:** The dirty air enters a cylindrical or conical chamber and is spun around at high speed. This creates a centrifugal force that causes the heavier particles to move toward the outer walls of the chamber, where they stick and collect on the walls. The clean air then exits the chamber.

Smog Towers

Also known as air purification towers or air-cleaning towers, these are large structures designed to reduce air pollution in densely populated urban areas. Two such towers are installed in Delhi.

- **Principle:** They work by drawing in polluted air and then using a variety of air purification technologies to remove harmful pollutants before releasing the clean air back into the environment.
- **Working:** The smog tower receives the contaminated air, which undergoes a purification process through various stages before it's released back into the environment.
- **Significance:** By filtering out harmful pollutants like particulate matter, nitrogen oxides, and volatile organic compounds, smog towers can help to reduce respiratory problems, cardiovascular disease, and other health issues that can result from exposure to polluted air.
- **Issues:** The smog towers are not a viable method to clean city's air. The government of Delhi had talked about 80% pollution reduction at inlet and outlet of the tower, but never mentioned the effect of distance from the tower.

Artificial Cloud Seeding

Artificial cloud seeding is a process that involves adding materials to clouds in order to encourage precipitation. This technique is often used in areas that experience drought or water scarcity, or to mitigate the effects of natural disasters like wildfires.

- **Working:** Chemicals like silver iodide or dry ice into the atmosphere from aeroplanes. These materials act as nuclei around which water droplets can condense, eventually forming precipitation.
- **Significance:** Artificial cloud seeding has been shown to raise precipitation levels by around 10% to 30% annually and is a more cost-effective method compared to desalination processes.
  - **Agriculture:** Cloud seeding can alleviate drought conditions by inducing rainfall in areas that are experiencing a lack of precipitation. Example: **Project Varshadhari** in **Karnataka** of 2017.
  - **Power generation:** Holds power generation capacity. In the past four decades, cloud seeding trials in Tasmania, Australia, have demonstrated an increase in hydroelectricity generation.
  - **Control water pollution:** Artificial cloud seeding has the potential to sustain the minimum summer river flows and mitigate the effects of treated wastewater discharges from industries and municipalities by diluting them.
  - **Fog dispersal:** "Project Sky Water" of the U.S.A. in 1962 for weather modification through cloud seeding aimed at fog dispersal, hail suppression, and cyclone modification

Technology to Address Stubble Burning

Turbo Happy Seeder (THS) machine has the ability to remove stubble from the field while also sowing new seeds. Once the stubble is removed, it is repurposed as mulch for the field.

Best practice: China

China has implemented several measures to combat air pollution, including:

- **Closure of coal-fired power plant**: China has shut down hundreds of coal-fired power plants in recent years and has pledged to close thousands more. This has helped to reduce the amount of pollution from coal-fired power generation.
- **Stricter emissions standards**: China has implemented stricter emissions standards for vehicles and industrial facilities, which has helped to reduce emissions of harmful pollutants.
- **Increased use of renewable energy**: China has rapidly increased its use of renewable energy sources, such as solar and wind power, in recent years. This has helped to reduce the country's reliance on fossil fuels and has helped to reduce air pollution.
- **Improved public transportation**: China has invested heavily in public transportation infrastructure, including high-speed rail, buses, and subways. This has helped to reduce the number of cars on the road and has helped to reduce air pollution.
- **Green building practices**: China has adopted green building practices, including the use of energy-efficient building materials and designs. This has helped to reduce energy consumption and has helped to reduce air pollution.

20

OZONE DEPLETION

OZONE LAYER AND ITS DEPLETION

Ozone

Three distinct forms of oxygen exist in the atmosphere; one of them is ozone. It is an inorganic oxygen molecule made up of three oxygen atoms and has the chemical formula **O3.** The name comes from the Greek word "ozein, meaning "to smell."

Formation and Destruction of ozone in the atmosphere

There are natural processes which create and destroy ozone in the atmosphere.

Formation of Ozone

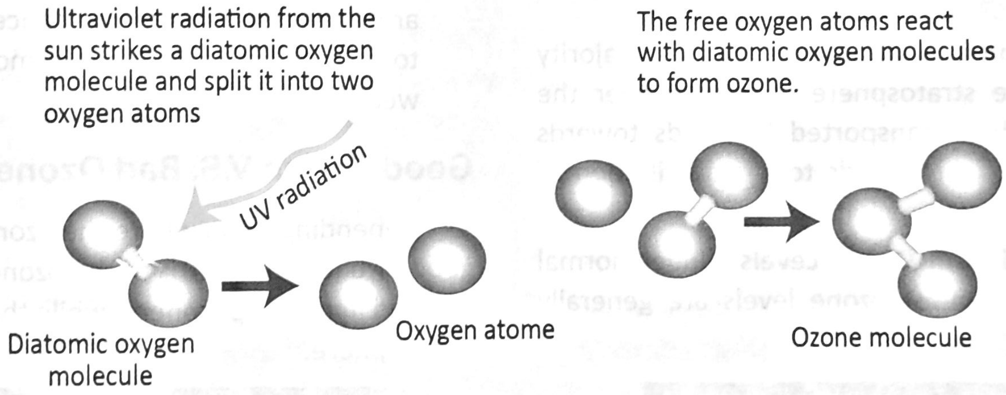
When oxygen molecules (O2) are struck by high-energy ultraviolet rays (UV-C), they split, resulting in the formation of two individual oxygen atoms called **atomic oxygen.** Next, a freed oxygen atom combines with another oxygen molecule, leading to the creation of ozone (O3). This process is known as **photolysis.**

- **Significance of the process:** It helps absorb high-energy ultraviolet radiation (UV-C) and blocks the harmful UV rays from reaching the Earth's surface.

Destruction of Ozone

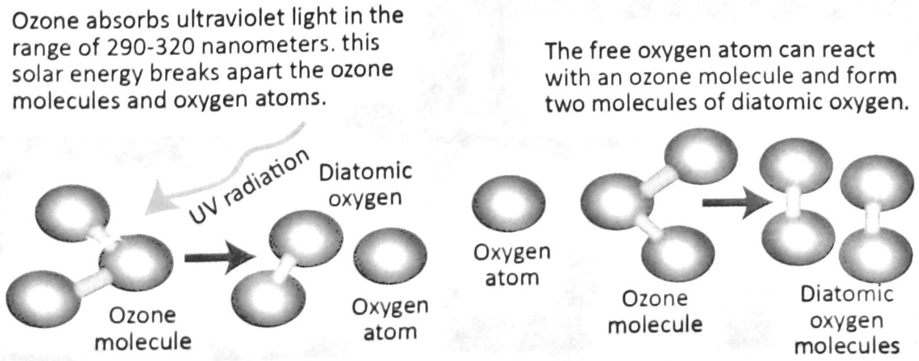
Ozone is naturally broken down in the stratosphere by sunlight. It gets destroyed when it reacts with molecules containing nitrogen, chlorine, hydrogen, or bromine.

Natural Ozone Production in the Stratosphere


Ultraviolet radiation from the sun strikes a diatomic oxygen molecule and split it into two oxygen atoms
UV radiation
Diatomic oxygen molecule
Oxygen atome
The free oxygen atoms react with diatomic oxygen molecules to form ozone.
Ozone molecule

Natural Ozone Production in the Stratosphere

Natural Ozone Destruction in the Stratosphere

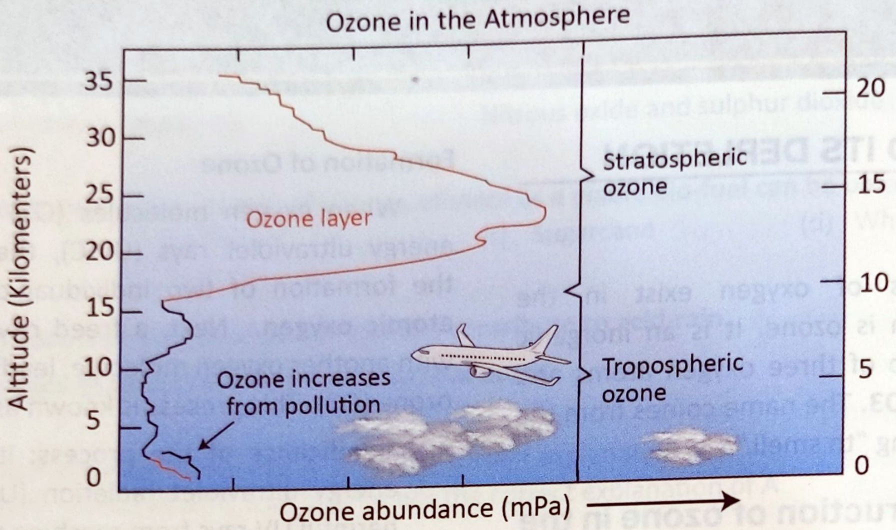

Ozone absorbs ultraviolet light in the range of 290-320 nanometers. this solar energy breaks apart the ozone molecules and oxygen atoms.
UV radiation
Diatomic oxygen
Ozone molecule
Oxygen atom
The free oxygen atom can react with an ozone molecule and form two molecules of diatomic oxygen.
Oxygen atom
Ozone molecule
Diatomic oxygen molecules

Natural Ozone Destruction in the Stratosphere

OZONE LAYER

The ozone layer or the ozonosphere, is a region in the stratosphere located approximately 15–30km above the Earth's surface, characterized by a high concentration of ozone.

- **Balance**: In an unpolluted atmosphere, there is a balance between the production and depletion of ozone. Consequently, the overall concentration of ozone in the stratosphere remains relatively stable.

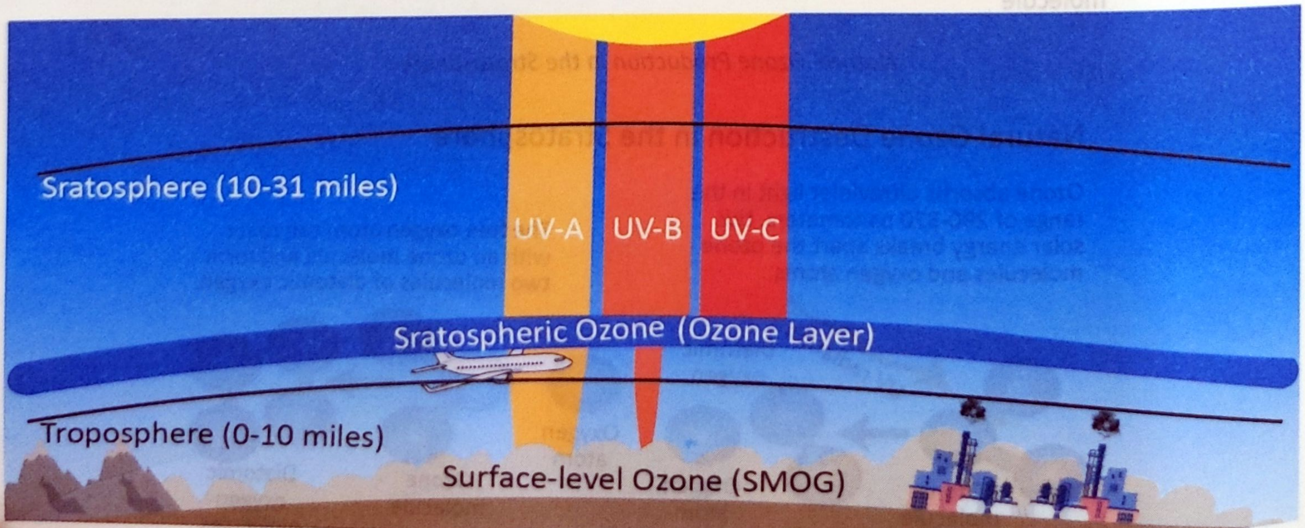


Ozone Layer

- **Variation with altitude**: There is a variation in the concentration of ozone in the stratosphere with altitude. The highest levels of ozone are generally observed between 19 and 23 km above the Earth's surface.
- **Ozone Formation and Transportation**: The majority of ozone in the stratosphere is formed over the equator. It is then transported by winds towards higher latitudes, which leads to a redistribution of ozone across different regions.
- **Regional Variation in Ozone Levels**: Under normal conditions, the highest ozone levels are generally found over the Canadian Arctic and Siberia. On the contrary, the lowest ozone concentrations are found over the Equator.
- **Daily Variations due to Weather Conditions:** There are daily variations in the concentration ozone due to factors such as air mass movements, and local weather conditions.

Good Ozone V.S. Bad Ozone

Depending upon where the ozone is found, it can be good or bad. About 10% of the ozone in the atmosphere is found in the troposphere; while the rest is found in the stratosphere.



Sratosphere (10-31 miles)
UV-A
UV-B
UV-C
Sratospheric Ozone (Ozone Layer)
Troposphere (0-10 miles)
Surface-level Ozone (SMOG)

Good Vs. Bad Ozone

Good Ozone	Bad Ozone
It is the stratospheric ozone.	It is the tropospheric ozone. Also known as ground-level/ surface-level ozone
It acts as a shield to protect Earth's surface from the sun's harmful ultraviolet radiation. The stratospheric ozone is often termed as **"Earth's sunscreen."**	It is harmful and one of the chief air pollutants. It is the main component of smog. It is not emitted directly into the air. It is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC).

Ozone Depletion

Ozone depletion occurs when the natural balance between the production and destruction of stratospheric ozone gets disturbed.

Brief Historical Background

- **1974:** For the first time, scientists Sherwood Rowland and Mario Molina warned that human-generated CFCs are harming the ozone layer.
- **1977:** The World Plan of Action on the Ozone Layer was adopted by the United Nations Environment Programme (UNEP) Governing Council. It called for intensive international research and monitoring of the ozone layer.
- **1985:** British Antarctic Survey scientists reported on the recurring springtime ozone hole over Antarctica.

DO YOU KNOW?

In 1994, the Nobel Prize for Chemistry was awarded to Sherwood Rowland, Mario Molina and Paul Crutzen for their pioneering work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone.

Ozone Depleting substances

Ozone depleting substances are gases that destroy ozone when they reach the ozone layer. They generally contain chlorine, bromine, fluorine, carbon, and hydrogen in varying proportions. They are often referred to as halocarbons.

List of Ozone Depleting Substances

Name	Uses
Chlorofluorocarbons (CFCs)	As coolants in refrigerators and air conditioners, As solvents in degreasers and cleaners Also used to dilute sterilant gas mixtures, In production of foams
Hydrochlorofluorocarbons	Used as a replacement of CFCs; mainly used as refrigerants
Halons	Used in fire extinguishers
Carbon Tetrachloride	Used as raw material for CFCs. Also used in fire extinguishers, as a dry-cleaning agent, Also, as an ingredient in pesticides, pharmaceuticals, paints and solvents.
Methyl Bromide	Used as a Fumigant
Methyl Chloroform	solvent in cleaners, degreasers and adhesives.
Bromochloromethane	Used in Fire extinguishers

Mechanism of Ozone Destruction in the Stratosphere

Ozone-depleting substances reach the stratosphere and undergo a series of transformative steps in the presence of intense UV radiation.

- **Breakdown of Ozone-Depleting Chemicals**: The high-energy solar UV radiation acts as a catalyst and breaks down ozone-depleting chemicals. Chlorine and bromine atoms, which are highly reactive, are released
- **Catalytic Reactions and Ozone Destruction:** These chlorine and bromine atoms engage in a complex sequence of catalytic reactions and result in the destruction of ozone molecules.

The Antarctic Ozone Hole

Ozone hole is not actually a hole where there is no ozone present. It is a region of exceptionally depleted ozone in the stratosphere over the Antarctic. This occurs at the beginning of Southern Hemisphere Spring (August–October). It is termed ozone hole when total ozone is 220 Dobson Units or lower.

As compared to the rest of the world, the South Antarctic region is more prone to ozone depletion, because of several reasons, such as:

- **Colder Temperature:** The temperature of the stratosphere is much colder in the Antarctic region as compared to the rest of the world. The cold temperate leads to the formation of **Polar Stratospheric Clouds (PSCs)**. These clouds intensify the depletion of the ozone layer in the region by providing a surface for the chemical reactions to occur, where stable Chlorine and Bromine compounds are converted into more reactive molecules that react with the ozone layer and deplete it.
- **Unique Atmospheric Conditions:** During the winter months, polar vortex forms over Antarctica. It is formed due to the temperature and pressure difference between the polar region and mid-latitudes. It is a large-scale circular pattern characterized by strong winds circling around the poles and trapping a mass of cold air inside. This circulating pattern accumulates the Chlorine and Bromine molecules that are further intensified by PSCs and destroy the ozone layer.

Why Arctic Ozone Layer depletion is less severe than the Antarctic?

There are mainly two reasons that make Arctic Ozone less severe:

- **Temperature:** The temperature in the Arctic region is not as cold as in the Antarctic region, due to which Polar Stratospheric Clouds are not formed on a large scale which is the largest factor for the Ozone depletion in the Antarctic region
- **Geography:** The Antarctic region is isolated and surrounded by the strong and continuous circumpolar vortex, which prevents the mixing of air between the polar region and mid-latitudes. On the other hand, the Arctic region is surrounded by land masses and no continuous and strong vortex is formed which allows for easy mixing of air with the other regions. This pattern dilutes the concentration of Ozone depleting substances in the Arctic region.

Impact of Ozone Depletion

Impact of Ozone Depletion	
On Human Health	• Sunburns, premature ageing of the skin. • Increase in melanoma and non-melanoma skin cancers • Increase in cataracts leading to damage to the eye vision resulting in blindness • Weakening of the human immune system
On agriculture and Forestry	• Many agricultural crops like are rice, wheat, soybean, corn, sweet corn, barley, oats, wheat, soybean, peas, carrots, etc. are sensitive to the UV-B radiation of the Sun. Increase in UV radiation affects the physiological and developmental processes of plants. • Number of commercially important trees also have UV-B radiation sensitivity.
On marine life	• Increased UVB radiation threatens the survival of phytoplankton. • UVB radiation also cause damage to early developmental stages of fish, shrimp, crab, amphibians, and other marine animals.
On Biogeochemical Cycles	• Increase in UVB radiation could affect terrestrial and aquatic biogeochemical cycles. This will in turn alter both sources and sinks of greenhouse and chemically important trace gases
On materials	• Various materials such as synthetic polymers are adversely affected by UVB radiation.

What is the impact of Ozone Depletion on Indian Monsoon?

the depleted ozone layer is a major concern for India due to its direct or indirect impact on the Indian Monsoon. The depleted Ozone layer can impact monsoons in the following ways:

- **Changes in atmospheric circulation:** Ozone depletion can lead to alterations in the atmospheric circulation, which can impact the Indian Monsoon. Research has shown that the depletion of the ozone layer in the polar regions can weaken the westerly winds over the Indian Ocean, potentially causing changes in the intensity and timing of the monsoon. Therefore, it is important to understand the link between ozone depletion and atmospheric circulation to better comprehend the effects on the Indian Monsoon.

- **Changes in Temperature:** The depletion of the ozone layer can result in temperature changes, which can have an impact on the Indian Monsoon. One study published in Nature in 2016 revealed that the thinning of the ozone layer over the Arctic can lead to the cooling of the northern hemisphere. This cooling effect can alter the temperature gradient between the land and sea, ultimately affecting the Indian Monsoon.

The Ozone Treaties

1985 The Vienna Convention for the Protection of the Ozone Layer is negotiated.

1987 The Montreal Protocol on Substances that Deplete the Ozone Layer is signed.

1990 The London Amendment sets the phase-out of CFCs, halons, and carbon tetrachloride by 2000 in developed countries, and by 2010 in developing countries. Methyl chloroform is added to the list of controlled ODSs.

1991 The Multilateral Fund is established to finance phase-out projects in A5 countries.

1992 The Copenhagen Amendment significantly accelerates the phase-out of ODSs and incorporates an HCFC phase-out for developed countries, beginning in 2004.

1993 The phase-out of HCFCs is accelerated for A2 countries to start ten years earlier at the Bangkok Meeting of the Parties.

1995 The phase-out of methyl bromide is set to 2010, and HCFC phase-out is moved from 2030 to 2020 for A2 countries at the Vienna Meeting of the Parties.

1997 The Montreal Amendment establishes the phase-out of HCFCs in developing countries, as well as the phase-out of methyl bromide in developed and developing countries in 2005 and 2015, respectively.

1999 The Beijing Amendment tightens controls on the production and trade of HCFCs and methyl bromide.

2007 The phase-out of HCFCs is accelerated for A2 and A5 countries at the Montreal Meeting of the Parties.

2008 The Dakar Declaration is adopted. It recognized the need to accelerate the phase-out of HCFCs and called for support to developing countries to help them comply with the Protocol's requirements.

2013 The Dubai Pathway is adopted in 2013. It aimed to accelerate the phase-out of HCFCs and promote the use of low-global warming potential alternatives.

2016 The Kigali Amendment is established, extending controls to phase down the production and consumption of hydrofluorocarbons (HFCs).

The Ozone Treaties

Vienna Convention for the Protection of the Ozone Layer

It is an international treaty which aims to protect human health and the environment against the adverse effects of human-induced modifications of the ozone layer. It was signed in 1985 and came into force in 1988. It has been ratified by 198 states (including India).

Key Features

- **Monitoring and Reporting:** It established global monitoring and reporting on ozone depletion.
- **Research Activities:** It promotes research activities, cooperation and the exchange of information between states.
- **Non-legally Binding:** It asks states to take appropriate measures to prevent activities that harm the ozone layer. However, it is not binding and does not provide any legally binding goals for states to phase out CFCs.

Montreal Protocol

Montreal Protocol on Substances that Deplete the Ozone Layer is a multilateral environmental agreement for protecting stratospheric ozone. It regulates the production and consumption of nearly 100 man-made ozone-depleting substances. It was agreed upon in 1987 and entered into force in 1989. It has been ratified by 198 states. Both Vienna Convention and Montreal Protocol are first universally ratified treaties in United Nations history.

Key Features

- **Phase-down of ODS:** The Protocol seeks to phase-down the consumption and production of the different ODS in a step-wise manner. The Parties to the protocol are provided different timetables for phasing out ODS. The different timetables are based on whether it's a developed or a developing country.
- **Responsibilities of Parties**: It includes phasing out of the different groups of ODS, control of ODS trade, annual reporting of data, national licensing systems to control ODS imports and exports.
- **Nature of Commitments**: Developing and developed countries have **equal but differentiated responsibilities.** Both the group of countries have binding, time-targeted and measurable commitments.
- **Assistance:** The Parties are assisted by the Ozone Secretariat. It is based at UN Environment Programme headquarters in Nairobi, Kenya.

Amendments to the Montreal Protocol:

There have been six amendments to the Montreal Protocol so far.

- **London Amendment (1990):** It called for complete phase-out of CFCs, carbon tetrachloride, and halons by 2000 in developed countries, and by 2010 in developing countries.
    - Methyl chloroform was also added to the list of controlled substances, with a phase-out elimination plan set for developed countries by 2005 and for developing countries by 2015.
- **Copenhagen Amendment (1992):** It significantly accelerated the phaseout of ODSs. It also incorporated an hydrochlorofluorocarbons (HCFC) phaseout for developed countries, beginning in 2004.
    - CFCs, carbon tetrachloride, halons, and methyl chloroform were targeted for complete phaseout in 1996 in developed countries.
    - Consumption of methyl bromide was capped at 1991 levels
- **Montreal Amendment (1997):** It included the phase-out of HCFCs in developing countries. It also included phase-out of methyl bromide in developed and developing countries in 2005 and 2015, respectively.
- **Beijing Amendment (1999):** It included Bromochloromethane for immediate phase out; it also introduced production controls on HCFCs as well as controls on trade with non-Parties.
- **Kigali Amendment (2016):** Under the agreement, the Parties committed to phase down 80-85 per cent production and consumption of Hydrofluorocarbons (HFCs) by the late 2040s.

Multilateral Fund for the Implementation of the Montreal Protocol (MLF)

It is a financial mechanism created in 1990 by the London Amendment. It aims to help developing countries meet in covering the additional costs associated with implementing the Montreal Protocol.

Success: Scientists from NASA and the US National Oceanic and Atmospheric Administration reported that the Antarctic ozone hole is shrinking. In the end of 2022, it spanned an average area of 23.2 million square kilometers.

DO YOU KNOW?

16 September every year is celebrated as **International Day for the Preservation of the Ozone Layer**, It commemorates the date when the Montreal Protocol on Substances that Deplete the Ozone Layer was signed in 1987.

India's Efforts to Address Ozone Depletion

India and Montreal Protocol

- India became a party to the Vienna Convention in 1991 and Montreal Protocol in 1992.
- **Ozone Cell:** The Ministry of Environment, Forest and Climate Change (MoEFCC) has established an Ozone Cell as a National Ozone Unit (NOU). It aims to provide necessary services for effective implementation of the Montreal Protocol in India.
- **Empowered Steering Committee (ESC):** It oversees the implementation of the Montreal Protocol provisions, review of policies and implementation of projects/plans and monitoring.

Ozone Depleting Substances (Regulation and Control) Rules, 2000

The Rules regulate the production, consumption, export and import of ODSs. The Rules have been amended in 2001, 2003, 2004, 2005, 2007, 2014 and 2019.

Key features:

- The Rules prohibit use of CFCs except for MDIs and for other medical purposes and use of halons except for servicing.
- It mandates compulsory registration of ODS producers, manufacturers of ODS based products, importers, exporters, stockists and sellers

India Cooling Action Plan

India is the first country in world to develop a Cooling Action Plan. It was launched in 2019. It aims to provide to **sustainable cooling and thermal comfort** for all while simultaneously safeguarding the environment and generating socio-economic advantages for society. It seeks to provide a **20- year perspective plan** and policy recommendations, to address the cooling requirement across various sectors.

Key Targets

- Reduce cooling demand across sectors by 20% to 25% by 2037-38,
- Reduce refrigerant demand by 25% to 30% by 2037-38,
- Reduce cooling energy requirements by 25% to 40% by 2037-38,
- Recognize "cooling and related areas" as a thrust area of research under national S&T Programme
- Training and certification of 100,000 servicing sector technicians by 2022-23, synergizing with Skill India Mission.

Ozone Depleting Gas Index (ODGI)

It was developed by the scientists of the **National Oceanic and Atmospheric Administration** (NOAA) in 1990s. It tracks the overall stratospheric concentration of ozone-depleting chlorine and bromine from long-lived ozone-depleting substances (ODS) relative to its peak concentration in the early 1990s. Separate ODGI values are reported for mid-latitudes and for Antarctica.

- According to the ODGI 2022, concentration of ozone-depleting substances in the atmosphere has reduced significantly.

DO YOU KNOW?

Sun Protection Factor (SPF) is a measure of how much solar energy (UV radiation) is required to produce sunburn on protected skin (i.e.., in the presence of sunscreen) relative to the amount of solar energy required to produce sunburn on unprotected skin. Higher SPF values correspond to greater sunburn protection.

21

WATER POLLUTION

Water pollution refers to the contamination of water bodies such as lakes, rivers, oceans, and groundwater caused by both human activities and natural processes. This contamination occurs when harmful substances such as chemicals, waste materials, and microorganisms are introduced into the water, making it unsuitable for human use and damaging aquatic life.

Depending upon the medium in which it occurs, water pollution can be classified into two types- Freshwater Pollution and Marine Pollution. Freshwater pollution can be further classified into Surface water pollution and groundwater pollution.

FRESHWATER POLLUTION

When pollutants enter a river, lake, or pond, it is known as **surface water pollution**. On the other hand, when pollutants find their way into an aquifer, it results in **groundwater pollution**. Freshwater bodies, including both surface water and groundwater, have low salt content, typically less than 5 parts per thousand (ppt).

Sources of Surface Water Pollution

Types of Sources

The sources of water pollution can be classified into Point Sources and Non-Point Sources.

- **Point sources** refer to pollution that originates from specific and identifiable locations. For example, a sewage outlet or factory drain. Such sources can be controlled effectively through technical interventions.
- **Non-point sources** refer to pollution that is not confined to a specific location but is rather spread out over larger areas. For example, water that flows from farms, grazing lands, construction sites, abandoned mines and pits, etc. Control of water pollution in such cases is challenging and requires constant and widespread efforts on a large scale.

Major Water Pollutants

Water pollutants can be broadly classified into disease-causing agents, oxygen-depleting wastes, inorganic plant nutrients, water soluble inorganic chemicals

- **Disease causing Agents:** These pollutants include various microorganisms such as bacteria, viruses, and protozoa. The primary source of such pollutants is untreated sewage and domestic waste. Examples of disease-causing agents include pathogens like Escherichia coli (E. coli), Salmonella, etc. These organisms can cause waterborne diseases such as cholera, gastrointestinal illnesses, typhoid fever, and diarrhea.
- **Oxygen Depleting Wastes**: The primary source of such wastes includes sewage, agricultural runoff, and industrial waste. They cause depletion of dissolved oxygen when they enter water sources. The wastes provide a food source for certain microorganisms, which consume oxygen during decomposition. This depletion of oxygen kills fishes and other forms of oxygen dependent aquatic life.
- **Inorganic plant nutrients:** These mainly include nitrogen and phosphorus compounds which primarily come from fertilizers, animal waste, and untreated sewage. Inorganic plant nutrients promote the growth of algae and leads to eutrophication.
- **Water soluble inorganic chemicals:** These include acids, salts, and toxic metals like mercury and lead. Increased concentrations of these chemicals make water unsuitable for drinking, adversely affect aquatic life, reduces crop productivity, and increases the corrosion of equipment utilizing such water.
- **Organic chemicals:** These include substances such as oil, plastics, cleaning solvents, and detergents. These chemicals have detrimental effects on both aquatic life and human health. The main source of such pollutants is industrial activities and improper disposal of chemical wastes.

- **Sediment or suspended matter:** It consists of insoluble particles like soil and other solids that become suspended in water.
- **Water-soluble radioactive isotopes:** They bioaccumulate and bio magnify as they move in food chains and webs and result in birth defects, cancer, and genetic damage.
- **Heat/Thermal Discharge:** Power plants and other industries like steel industry, paper industry release hot water into nearby water bodies. This leads to a temperature increase in the water body. This reduces oxygen solubility and leads to disruption in the breeding cycle of aquatic organisms. This is known as **thermal pollution.**

List of **Major sources of water pollution and associated chief pollutants**

Cause	Chief Pollutants
Untreated disposal of Domestic wastewater and sewage	Disease-causing agents (bacteria, virus, protozoa), phosphates (a major ingredient in detergents) etc.
Untreated Industrial Waste	Heavy metals, acids, caustics, salts, metals solvents, chemicals, heated water and oils
Agricultural Runoff	Fertilizers, pesticides containing nitrates and phosphates
Soil erosion, deforestation, and construction activities	Sediments, suspended matter
Nuclear Waste	Radioactive substances

What are the main causes of water pollution in River Ganga?

- **Industrial Effluents:** One of the major reasons for pollution in the River Gangs is disposal of untreated or inadequately treated effluents from industries. For example, the discharge of toxic chemicals and heavy metals from textile factories in Kanpur and tanneries in Kanpur and Kolkata contaminate the river.
- **Sewage and Domestic Waste:** Untreated sewage and domestic waste from urban areas and towns along the river are major sources of pollution. In January 2023, at least 71% of the Ganga's monitoring stations reported alarming levels of faecal coliform (group of bacteria found in the gut and faeces of warm-blooded animals).
- **Agricultural Runoff**: The use of fertilizers, pesticides, and herbicides in farming leads to the contamination of the Ganga water through runoff. Excessive nutrient runoff, such as nitrogen and phosphorus, cause algal blooms and oxygen depletion. The use of pesticides further contributes to chemical contamination.
- **Religious and Ritual Practices**: Immersion of idols made from non-biodegradable materials and dumping of religious offerings, such as flowers and garlands, during religious ceremonies add to the pollution burden. For example, the immersion of idols during festivals like Durga Puja and Ganesh Chaturthi, especially in major cities like Kolkata and Varanasi, releases toxic substances into the river.
- **Solid Waste Dumping**: Improper disposal of solid waste, including plastics, in and around the river is a significant source of pollution. Garbage, including plastic bags and bottles, discarded by tourists and residents along the riverbanks, eventually finds its way into the river.
- **Deforestation and Soil Erosion**: Deforestation and soil erosion in the catchment areas of the river Ganga contribute to increased sedimentation and nutrient runoff, impacting water quality.

Groundwater Pollution

Groundwater Pollution occurs when harmful substances infiltrate and pollute the underground water reservoirs.

Causes of Groundwater Pollution

- **Geogenic Causes:** These are naturally occurring processes that can contaminate groundwater. Geological formations and mineral deposits often release harmful substances into the water. For example, several districts in West Bengal, such as Murshidabad and Nadia, have experienced high levels of arsenic contamination in groundwater. This has primarily resulted from the release of naturally occurring arsenic from sedimentary deposits.
- **Wastewater Discharge**: Improper municipal waste disposal, sewerage leads to the contamination of groundwater sources. India has witnessed instances of domestic water discharge causing groundwater contamination, such as:
- **Untreated Industrial Discharge:** Industries often discriminately dispose of untreated waste into water bodies, which can infiltrate and contaminate groundwater. For example, in the industrial town of Vapi, Gujarat there has been groundwater contamination due to the discharge of untreated industrial effluents. The contamination includes heavy metals such as mercury, chromium, and lead etc.
- **Agricultural Discharge**: Excessive use of fertilizers, pesticides, poor irrigation management, often lead to groundwater depletion and contamination. For

example, in Punjab, the intensive use of pesticides and herbicides has led to the contamination of groundwater.

- **Saltwater Intrusion**: It occurs when saline water infiltrates freshwater aquifers making groundwater unsuitable for usage. overexploitation of groundwater and sea-level rise are major contributing factors to saltwater intrusion. For example, parts of Tamil Nadu's coastal regions, including the districts of Chennai and Thoothukudi, have faced saltwater intrusion into groundwater.

Chart showing Groundwater Contaminants, impact and areas affected in India

Groundwater Pollutant	Regions Affected	Health Impact
Arsenic	West Bengal, Bihar, Assam, Uttar Pradesh	Arsenicosis, cancer, cardiovascular diseases
Fluoride	Andhra Pradesh, Tamil Nadu, Uttar Pradesh, Gujarat, and Rajasthan	Dental fluorosis, skeletal fluorosis, Knock-knee syndrome
Nitrate	Punjab, Haryana, Uttar Pradesh, Bihar	Methemoglobinemia (blue baby syndrome)
Uranium	Punjab, Haryana, Uttar Pradesh, Rajasthan, Tamil Nadu, Madhya Pradesh.	Kidney damage, increased cancer risk, developmental issues
Iron and Manganese	West Bengal, Tamil Nadu, Orissa, Uttar Pradesh and Bihar	Stomach disorders, liver damage, reduced cognitive abilities
Mercury	Tamil Nadu, Kerala, Karnataka, Maharashtra	Minamata Disease, kidney damage, reproductive issues
Cadmium	Punjab, Haryana, Telangana	Itai Itai (Ouch-Ouch Disease)

MARINE POLLUTION

Marine water bodies contain a high concentration of salt, equal to or greater than that of seawater (35 ppt or more). Estuaries and brackish waters fall in between these two categories, with salt content ranging from 5 to 35 ppt. Pollution of oceans, seas, estuaries, salt marshes, and other similar water bodies is known as marine pollution or ocean pollution.

Causes of Marine Pollution

- **Oil Spills:** They occur when refined petroleum products or crude oil are accidentally or intentionally released into the ocean from ships or offshore drilling rigs. Oil spills forms a coating over water surface and suffocates marine organisms. For example, in 2010, Deepwater Horizon oil spill in the Gulf of Mexico released large quantity of oil into the ocean. As a result, marine ecosystems, fisheries and coastal communities were disrupted.
- **Chemical Runoff:** Pesticides, fertilizers, herbicides from agriculture, and other chemicals from industrial activities that flow into rivers eventually reach the ocean. The chemicals pollute the seas and oceans, affecting the health and reproduction of marine organisms. For example, excessive use of fertilizers leads to nutrient enrichment in rivers, eventually leading to harmful algal blooms and dead zones in coastal waters.
- **Sewage and Wastewater Discharge:** Untreated sewage and wastewater discharged into the ocean and cause marine pollution. These contaminants are responsible for degrading water quality and harming marine life. For example, coastal areas near densely populated cities of developing countries with inadequate wastewater treatment systems, often experience high levels of contamination from urban wastewater.
- **Atmospheric Deposition:** Airborne pollutants like heavy metals, toxic chemicals from industrial emissions, fossil fuel combustion, and agricultural activities can travel over long distances. They can then deposit into the ocean through precipitation or atmospheric fallout. For example, mercury emissions from coal-fired power plants are carried by air currents and deposited into oceans.
- **Seabed Mining:**
  - It releases sediment plumes into the water column which are extremely harmful for benthic organisms and also reduces water clarity.
  - It releases harmful chemicals such as flocculants and reagents which are used to extract minerals from the seabed. It can also introduce contaminants, such as heavy metals or other harmful substances

- It can lead to physical disturbance of delicate and sensitive habitats, such as coral reefs, hydrothermal vents, and seamounts.
- The mining process can result in the deposition of fine sediments on the seabed, leading to siltation.

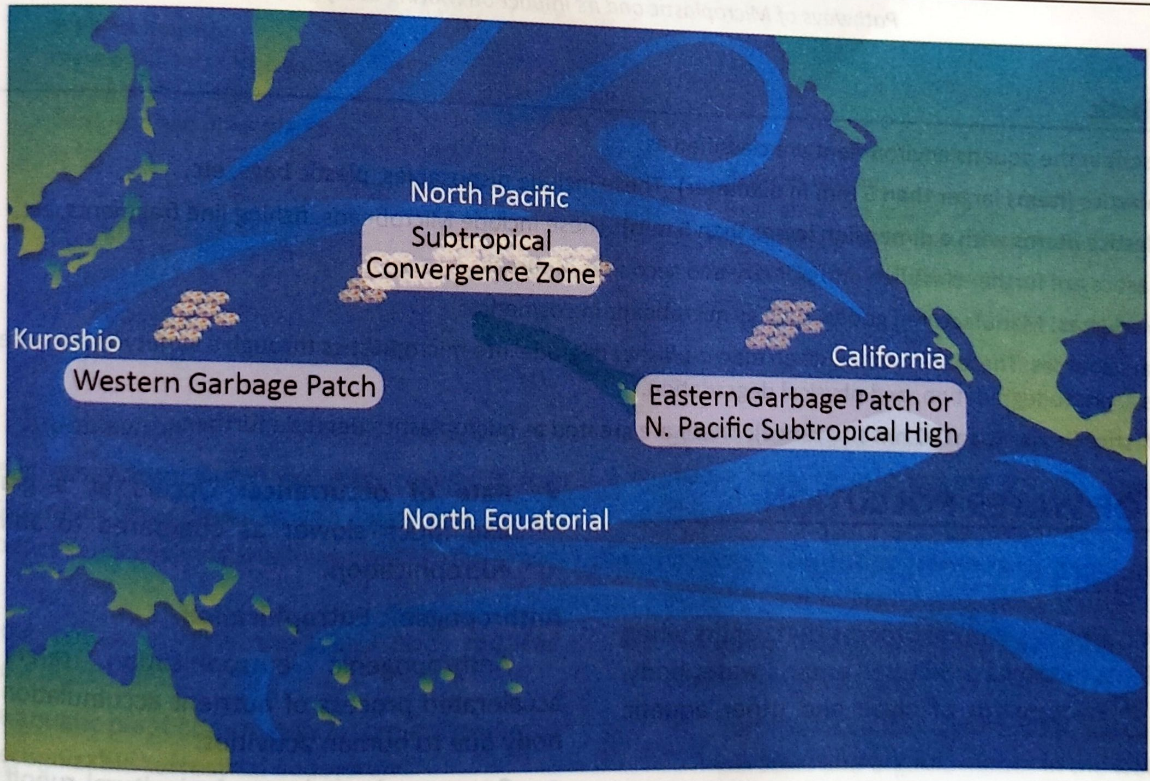
Marine Plastic Pollution

Extent of Marine Plastic Pollution

The United Nations (UN) has called marine plastic pollution a **"planetary crisis"**. According to UN, at least 14 million tons of plastic end up in the ocean every year. Further, plastic makes up 80% of all marine debris found from surface waters to deep-sea sediments.

Plastics that are more buoyant remain near to the ocean's surface. It is believed that only 1% of marine plastics float at or near the ocean's surface. The concentration rises in a specific mid-oceanic zone near the gyres (a large system of circular ocean currents). Because of the lack of movement in the region, plastic debris tends to gather and form "garbage patches". There are five major garbage patches:

Garbage Patch	Location
North Pacific Garbage Patch (also known as the Great Pacific Garbage patch) *It is the largest in the world.	The North Pacific Gyre (in the North Pacific Ocean between California and Hawaii)
South Pacific Garbage Patch	South Pacific Gyre (in the South Pacific Ocean between Australia and South America)
North Atlantic Garbage Patch	North Atlantic Gyre (spreads from the equator to Iceland, North American, Europe, and Africa)
The South Atlantic Garbage Patch	South Atlantic Gyre
The Indian Ocean Garbage Patch	Indian Ocean Gyre


North Pacific
Subtropical Convergence Zone
Kuroshio
Western Garbage Patch
California
Eastern Garbage Patch or N. Pacific Subtropical High
North Equatorial

Ocean Garbage

Sources of Marine Plastic Pollution

- **Land-based Sources:** It includes urban and stormwater runoff, sewage, littering, improper waste disposal and management, industrial activities, construction waste, etc. Additionally, natural disasters such as hurricanes and tsunamis can result in significant amounts of plastic waste entering the ocean, through overflowing landfills and damaged waste management systems.
- **Ocean-based Sources**: It includes wastes from fishing industry, shipping activities and aquaculture.

Types of plastic

Plastics present in the aquatic environment are classified as:

- **Macroplastics (items larger than 5 mm in diameter)-** These include disposables, plastic bags, etc.
- **Microplastics (items with a dimension lesser than 5 mm):** These include Microbeads, fishing line fragments, etc.
- Microplastics are further classified into primary and secondary sources.
- **Primary sources**: Manufactured goods, such as microbeads in cosmetics.
- **Secondary sources**: These are created when macro-plastics degrade into microplastics through a variety of processes including hydrolysis, photodegradation, and physical degradation.
- **Nano plastics (lesser than100 nm size range):** These are created as microplastics degrade further.

IMPACT OF WATER POLLUTION

Eutrophication

Eutrophication is a natural process that occurs when excess nutrients (artificial or natural) enter a water body, leading to an overgrowth of algae and other aquatic plants.

Causes of eutrophication

Natural Eutrophication

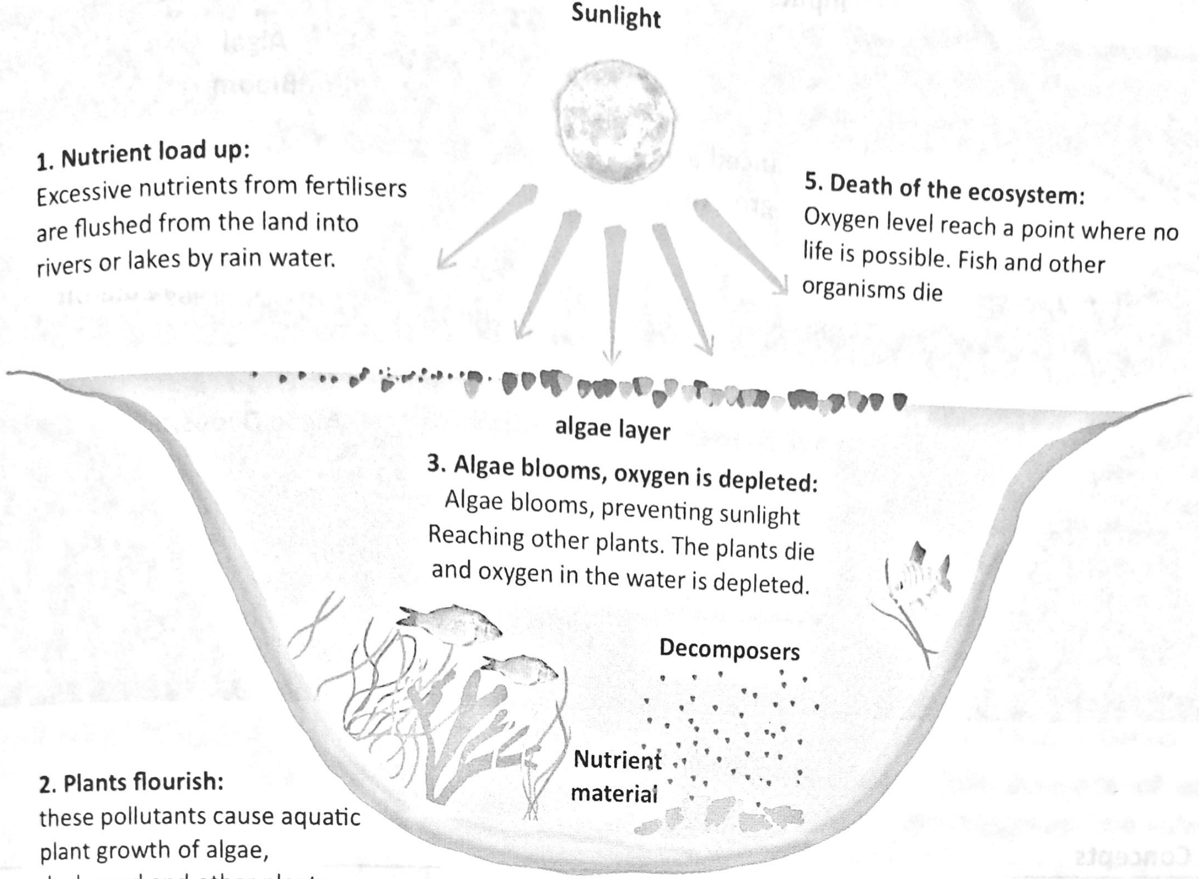
Natural eutrophication refers to the gradual process of nutrient accumulation in a water body over a long period of time (over centuries).

- **Sources of nutrients:** Weathering of rocks and soils and decaying organic matter are the prime sources of nutrients for natural eutrophication.
- **Rate of occurrence:** Occurs at a gradual pace and much slower as compared to anthropogenic eutrophication.

Anthropogenic Eutrophication

Anthropogenic eutrophication refers to the accelerated process of nutrient accumulation in a water body due to human activities.

- **Sources of nutrients:** Agricultural runoff, untreated industrial and domestic sewage into water bodies lead to anthropogenic eutrophication.
- **Rate of occurrence:** Occurs at a very fast rate.



1. Nutrient load up:
Excessive nutrients from fertilisers are flushed from the land into rivers or lakes by rain water.

2. Plants flourish:
these pollutants cause aquatic plant growth of algae, duckweed and other plants.

3. Algae blooms, oxygen is depleted:
Algae blooms, preventing sunlight Reaching other plants. The plants die and oxygen in the water is depleted.

4. Decomposition further depletes oxygen:
Dead plants are broken down by bacteria Decomposers, using up even more oxygen in the water.

5. Death of the ecosystem:
Oxygen level reach a point where no life is possible. Fish and other organisms die

Process of Eutrophication

Impacts of Eutrophication

- **Change in ecosystem:** Eutrophication results in the formation of detritus layer in the lakes and ponds and produces successively shallower depth of surface water.
  - In due course of time, the water body reduces into a marsh land.
  - The aquatic plant community is transformed into a recognizable terrestrial ecosystem.
- **Death of aquatic animals and plants:** Eutrophication leads to algal bloom that restricts the penetration of sunlight which results in the death of aquatic plants.
- **Reduced oxygen replenishment:** With the death of the aquatic plants the photosynthesis process stops resulting in reduced oxygen supply to the water.
- **Species invasion:** The abundance of nutrients in the water body transforms the species composition of the ecosystem.
- **Toxicity:** The toxins released by some algal blooms poses threat to both human and aquatic organisms.
- **Turbidity:** Transparency in the water is drastically reduced and turbidity increases.
  - Turbidity is caused by the presence of suspended particles and organic matter in the water column.
  - When turbidity is low, more light can penetrate through the water column. This creates optimal conditions for algal growth and vice-versa.
- **Loss of coral reefs:** Eutrophication leads to increased turbidity and turbidity affects the survival of the corals.

Healthy vs Eutrophic System

Important Concepts

Algal Bloom: An algal bloom or marine bloom or water bloom refers to rapid increase in the population of algae in an aquatic ecosystem. **Harmful Algal Blooms** (HABs) occur when large colonies of algae grow rapidly over a water body and produce harmful toxins. The toxins can have a detrimental effect on marine life, birds as well as human beings.

Dead Zones: These are areas of water bodies where aquatic life cannot survive because of low oxygen levels. Dead zones are generally caused by significant nutrient pollution. The largest dead zone in the world lies in the Arabian Sea, covering almost the entire 63,700-square mile Gulf of Oman. The second largest is in the Gulf of Mexico in the United States

Red tide: It is a phenomenon caused by algal blooms during which algae growth is extensive. The red tide leads to discoloration of coastal waters.

Blue Tide: It is a phenomenon when the luminescent marine phytoplankton (commonly known as dinoflagellates) makes the sea appear deep blue. The phenomenon is prominent in the night.

- **Bioluminescence**: It is the property of a living organism to produce and emit light. It is found in many marine organisms such as bacteria, algae, jellyfish, worms, crustaceans, sea stars, fish and sharks.
- **Significance of Blue tide:**
    - The blue tide phenomenon signifies climate change.
    - It also indicates the degraded quality of the marine ecosystem. The particular type of phytoplankton shows up where seawater has low dissolved oxygen and high presence of Nitrogen.

On human health

According to the United Nations, every year there are more deaths caused by polluted water than all types of violence combined. Contaminated water carries bacteria and viruses that cause the spread of water-borne diseases.

- **Waterborne diseases:** Contaminated water can carry harmful bacteria, viruses, and parasites that cause diseases such as cholera, typhoid fever, and dysentery. These diseases can cause diarrhea, dehydration, and other severe health problems, particularly in people with weakened immune systems.
- **Chemical exposure:** Polluted water can contain harmful chemicals, such as heavy metals, pesticides, and industrial pollutants. Exposure to these chemicals through drinking water, swimming, or consuming contaminated fish and shellfish can cause a range of health problems, including cancer, neurological damage, and reproductive disorders.

- **Skin irritation:** Swimming or bathing in polluted water can cause skin irritation and other dermatological problems, particularly in people with sensitive skin or allergies.
- **Respiratory problems:** Contaminated water can release harmful gases such as hydrogen sulfide and methane, which can cause respiratory problems such as coughing, wheezing, and shortness of breath.
- **Chronic diseases:** Long-term exposure to polluted water can lead to chronic health problems such as kidney damage, liver damage, and neurological disorders.
- **Mental health:** The impact of water pollution can also have a negative impact on mental health, leading to anxiety and depression as people feel helpless and overwhelmed by the consequences of pollution.

On Economy

Water pollution can have a significant impact on the economy of a country, as it can affect various sectors and industries. Here are some of the ways water pollution can impact the economy:

- **Loss of tourism revenue:** Water pollution can make beaches, lakes, and rivers unattractive to tourists, reducing the revenue generated by tourism.
- **Increased healthcare costs:** Water pollution can lead to various health problems, such as skin irritation, respiratory problems, and even cancer. This can increase healthcare costs for individuals and the government.
- **Damage to fisheries:** Water pollution can harm fish populations and reduce the amount of seafood that can be harvested. This can affect the fishing industry and the communities that depend on it.
- **Reduced agricultural productivity:** Water pollution can contaminate soil and make it difficult to grow crops. This can lead to reduced agricultural productivity, affecting the food supply and increasing food prices.
- **Increased costs for water treatment:** Water pollution can make it more expensive to treat and purify water for domestic and industrial use. This can increase the cost of water for households and businesses.
- **Decreased property values:** Water pollution can make nearby properties less desirable, which can reduce property values and affect the real estate industry.

Impact of Marine Plastic Pollution

- **Ingestion:**
  - Numerous aquatic organisms consume plastics, which can result in physical harm or obstruction of their digestive systems. This, in turn, can lead to infections, starvation, diminished reproductive capacity, and even death. Microplastics have been discovered in the digestive systems of dead sea birds, turtles, whales, and other animals.
  - Further, microplastics, due to their small size, can evade wastewater filtration and treatment processes, entering natural habitats where they pose a threat to the food chain.
  - Exposure to microplastics can lead to stunted growth or behavioral changes in certain organisms.
- **Entanglement:** Marine animals face fatal consequences when they become entangled in nets, ropes, and other forms of plastic debris.
- **Impact on Corals**: The presence of accumulated plastics in coral reefs heightens the vulnerability of corals to diseases. This occurs as the plastics obstruct the passage of light and oxygen, vital for the health and survival of coral ecosystems.
- **Impact on Human Health**: Contaminants from plastic waste gradually accumulate within the marine food chain. Over time, these contaminants can be transferred to humans through the consumption of seafood, posing a potential public health concern.
- **Economic Impact:**
  - Plastic waste has a negative impact on tourism as it diminishes the attractiveness of coastal cities and islands.
  - The need for beach clean-up initiatives and waste management in marinas and harbors also incurs substantial economic costs.
  - Plastic waste poses navigational hazards, damaging propellers and engines of vessels.
  - Discarded or lost fishing nets contribute to "ghost fishing," resulting in reduced fishery stocks and significant economic losses for coastal fishing communities.

GLOBAL MEASURES TO COMBAT WATER POLLUTION

London Convention

The London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) was adopted in 1972 and entered into force in 1975. 87 states (not including India) are party to the Convention.. It aims to promote the effective control of all sources of marine pollution. It also seeks to take all practicable steps to prevent pollution of the sea by dumping of wastes and other matter.

United Nations Convention on the Law of the Sea (UNCLOS)

It is an international treaty that governs the use and management of the world's oceans and seas. The treaty was adopted in 1982 and entered into force in 1994, and has been ratified by 168 countries (including India).

Key features of UNCLOS:

- UNCLOS establishes the legal framework for activities in the oceans and seas, including fishing, shipping, and exploration and exploitation of natural resources.
- The treaty recognizes the rights of coastal states over their territorial waters and exclusive economic zones, and sets out rules for the delimitation of maritime boundaries between adjacent states.
- The treaty also establishes the International Tribunal for the Law of the Sea (ITLOS), to hear disputes related to the interpretation and application of UNCLOS.

International Maritime Organization

Founded in 1958, it is a global standard setting authority for the safety, security and environmental performance of international shipping. It aims to improve the maritime safety and prevention of maritime pollution. IMO measures accidental and operational oil pollution.

International Convention for the Control and Management of Ships' Ballast Water and Sediments

Adopted in 2004, it aims to prevent the spread of harmful aquatic organisms from one region to another and halt damage to the marine environment from ballast water discharge. There are 86 member states. India is not a party to the Convention.

Ballast water

It is water carried in ship's ballast tanks to improve its stability and balance. Ballast water is regarded as one of the most important mediums for spread of potentially invasive alien species.

International Convention for the Prevention of Pollution from Ships (MARPOL)

Developed by IMO, it was adopted in 1973. There are 158 parties, including India. It is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. It lists various forms of marine pollution caused by oil, noxious liquid substances, harmful substances in packaged form, sewage and garbage from ships, etc.

UN High Seas Treaty

It is a legally binding international agreement being developed within the framework of the United Nations Convention on the Law of the Sea (UNCLOS). The treaty will work as an implementation agreement under the UNCLOS, much like the Paris Agreement works under the UNFCCC. The treaty is also known as the agreement on "**biodiversity beyond national jurisdictions**", or BBNJ, as the high seas are open ocean areas that are outside the jurisdiction of any country.

- **Aim**: It aims to provide a comprehensive legal framework to protect oceans and marine life, particularly in the high seas, which were previously not covered by any such framework.
- **Significance:** The treaty is significant in achieving the 30x30 target set at UN CBD (Convention on Biological Diversity) COP15 under which the countries agreed to protect 30% of oceans by 2030.

Key features of the treaty:

Key features of the treaty	
Demarcation of Marine Protected Areas (MPAs)	• The treaty will establish a mechanism for demarcation of MPAs to conserve and protect marine environment and biodiversity. • MPAs are where ocean systems, including biodiversity, are under stress, either due to human activities or climate change. • These can be called the national parks or wildlife reserves of the oceans.
Access and Benefit-sharing Committee	• The committee will frame guidelines for the access and sharing of benefits derived from marine genetic resources beyond national jurisdiction.
Clearing-House Mechanism (CHM)	• The treaty establishes a CHM that will facilitate the sharing of information among member states on the access and benefit-sharing of marine genetic resources beyond national jurisdiction.
Environmental Impact Assessments	• Signatories will have to conduct environmental impact assessments before the exploitation of marine resources beyond national jurisdiction.
Consent from Indigenous Community	• The treaty mandates that the marine resources in areas outside national jurisdiction, which belong to indigenous individuals and local communities, can only be accessed with their free, informed consent and or approval and involvement". • By doing so, the treaty recognizes the important role of indigenous communities in the sustainable management of marine resources.
Special fund for developing countries	• A special fund will be established as part of the pact, which will be fixed by the conference of parties (COP). • The COP will also oversee the functioning of the treaty. • The fund will provide financial support for developing countries to participate in the implementation of the treaty.

High Seas: These are areas of oceans that lie beyond a country's Exclusive Economic Zone (that extends up to 200 nautical miles (370 km) from the coastline). The high seas are also known as international waters or the open ocean. No country is responsible for the management and protection of resources on the high seas. The high seas comprise 64 per cent of the ocean surface, and about 43 per cent of the Earth.

Other Measures

- **Convention on Continental Shelf 1964:** It defines and delimits the rights of States to explore and exploit the natural resources of the continental shelf.
- **Convention on Fishing and Conservation of Living Resources of the High Seas 1966:** It was designed to solve the problems involved in the conservation of living resources of the high seas.
- **Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention):** It was adopted in Helsinki in 1992. It aims to strengthen international cooperation and implement national measures for the sustainable management and protection of transboundary waters.
- **Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA):** Adopted in 1995, it is the only intergovernmental mechanism that directly addresses the connectivity between terrestrial, freshwater, coastal and marine ecosystems.
- **World Health Organization's (WHO) Global Water Quality Guidelines:** These guidelines provide a framework for assessing and managing water quality worldwide. They aim to prevent water pollution and ensure the safety of drinking water by providing guidance.
- **World Bank's Water Global Practice:** This initiative seeks to promote sustainable water management practices in developing countries. It offers technical assistance and financial support to countries to help them improve their water management practices.
- **United Nations' Sustainable Development Goal 6:** It focuses on ensuring the availability and sustainable management of water and sanitation for all. It strives to improve access to safe and affordable drinking water, enhance sanitation, and promote sustainable water management practices.

MEASURES TAKEN IN INDIA TO COMBAT WATER POLLUTION

- **Water (Prevention and Control of Pollution) Act:** Enacted in 1974, it aims to prevent and control water pollution in India. It also seeks to preserve and restore water resources of the country. The Act forbids discharging dangerous or contaminating matter, directly or indirectly, into any stream, well, sewer, or land.
- **National Water Policy (2012):** The policy emphasizes the importance of rainwater harvesting and water conservation. It also suggests for the scientifically planned preservation of rivers, water bodies, and associated infrastructure, with active involvement from local communities.
- **National Water Quality Monitoring Programme (NWMP):** CPCB in association with State Pollution Control Boards (SPCBs) and Pollution Control Committees monitor water quality across the country under the NWMP.
- **PRAYAG:** It stands for Platform for Real-time Analysis of Yamuna, Ganga and their Tributaries. It is a real-time monitoring centre for planning and monitoring projects and river water quality through various online dashboards.
- **Atal Bhujal Yojana:** The Atal Bhujal Yojana was launched in 2019 in collaboration with the World Bank to improve groundwater management in India. It is the world's largest community-led groundwater management program.
- **Atal Mission for Rejuvenation and Urban Transformation (AMRUT):** The Mission focuses on the development of important urban infrastructure in AMRUT cities, including water supply, sewerage and septage management, storm water drainage, green spaces and parks, and non-motorized urban transportation.
- **Aquifer Mapping and Management Programme:** Launched by CPCB in 2012, it aims to prepare aquifer specific groundwater management plans.

Water purification:

- The aquatic weed and invasive plant **water hyacinth** can purify water by eliminating toxic chemicals and heavy metals.
- **Bregoli,** (a paper industry byproduct that looks like sawdust), **oil zappers,** and microorganisms, can be used to clean up oil spills in water.
- **Eucalyptus trees** planted along the edges of sewage ponds can absorb excess wastewater quickly and release pure water vapor into the atmosphere.

Namami Gange

Launched in 2014, it is flagship programme of the Government of India It aims at effective abatement of pollution, conservation and rejuvenation of National River Ganga. The United Nations (UN) has recognized Namami Gange initiative as one of the top 10 World Restoration Flagships to revive the natural world. The 'Namami Gange' has also been called as the "beacon of hope" and an inspirational story at the recently held UN 2023 Water Conference.

- **Namami Gange Phase II (2021-26)**
  - Under the second phase, the states will prioritize the timely completion of projects and the preparation of bankable Detailed Project Reports (DPRs) for initiatives in towns situated along the Ganga tributaries.
  - Emphasis is placed on the restoration of small rivers and wetlands. Each Ganga district is required to formulate a scientific plan and health card for a minimum of 10 wetlands. Further, policies for the reuse of treated water and other byproducts also have to be adopted.
- **Implementation:** The Environment Protection Act (EPA), 1986, puts forward a five-tier structure to undertake measures to prevent, control and abate environmental pollution in the Ganga River. This includes
  - National Ganga Council under the chairmanship of Prime Minister of India
  - Empowered Task Force (ETF) under the chairmanship of Union Minister of Jal Shakti
  - National Mission for Clean Ganga (NMCG)
  - State Ganga Committees
  - District Ganga Committees
- **Clean Ganga Fund:** In 2015, the Clean Ganga Fund (CGF) was established as a trust under the Indian Trusts Act, 1882. Its purpose is to facilitate contributions from Resident Indians, Domestic and Overseas Corporates/Trusts, as well as NRIs/PIOs, towards the conservation efforts aimed at protecting the River Ganga.

Arth Ganga

The concept was first introduced during the first National Ganga Council by the Prime Minister of India. Arth ganga focuses on the sustainable development of the Ganga and its surrounding areas, by focusing on economic activities related to the river.

- **Principle:** The Arth Ganga model works on the principle of using economics to connect people with the river Ganga.
- **Objective:** To generate 3% of the GDP from the river Ganga itself.

Features of Arth Ganga Model

- **Cultural Heritage & Tourism**: Aims to introduce boat tourism through community jetties, promotion of yoga, adventure tourism etc. and Ganga Aartis.
- **Monetization and Reuse of Sludge & Wastewater**: Envisages reuse of treated water for irrigation, industrial purposes and revenue generation for ULBS
- **Zero Budget Natural Farming**: Includes chemical-free farming for 10 kms on either side of the river, Generating "more income, per drop", 'Gobar Dhan' for farmers,
- **Institutional Building**: By enhancing the local capacities for better decentralized water governance.
- **Public Participation**: To ensure increased synergies between stakeholders,
- **Livelihood Generation Opportunities**: Such as 'Ghat Mein Haat' Promotion of local products, Ayurveda, medicinal plants and etc. and Capacity building of volunteers like Ganga Praharis.

Other Developments:

- **Ganga Gram:** Launched in 2017, it is a project for sanitation based integrated development of all 4470 villages along the River Ganga.
- **Bhuvan-Ganga Web App:** Launched in 2015, it is a mobile application developed by ISRO. It aims to enable public to collect and report information on various pollution sources that affects the water quality of river Ganga.
- **Ganga Praharis:** These are a group of volunteers, who have been trained to provide on-the-ground support for conservation initiatives.
- **Ganga Tarini and Ganga Darpan**: Floating interpretation center "Ganga Tarini" and interpretation center "Ganga Darpan" have been established to raise awareness about biodiversity conservation and the rejuvenation of the river Ganga.
- **Ban on Waste Disposal:** In 2017, National Green Tribunal (NGT) banned the dumping of any waste within 500 metres of the Ganga. It also declared the river's stretch between Uttarakhand's Haridwar to Uttar Pradesh's Unnao as a No-development zone.

CHAPTER

22

WATER SCARCITY IN INDIA

WATER STRESS IN INDIA

India is home to 18 percent of the world's population, but only 4 percent of world's water resources, making it among the most water-stressed in the world. A significant proportion of the Indian population face high to severe water stress.

Key Concepts

- **Water Scarcity**: It occurs when there is a high ratio of water consumption to available water resources in a particular area. It is defined as a lack of safe water supplies. It may be an outcome of a large and growing population and consequent greater demands for water, and unequal access to it. For example, Rajasthan is facing water scarcity due to less availability of water resources and increasing pressure on groundwater.
- **Water Crisis:** It is a water-related challenge. It may be water scarcity, water stress, drought, flooding, etc. For example, states like Rajasthan, Haryana, Punjab, Madhya Pradesh, and Maharashtra are facing the problem of water crisis due to climate change and depleting groundwater resources.
- **Water Stress**: It is a broader concept and water scarcity is one of the indicators. It occurs when the human ecological demand for water is more than the available amount of water resources during a certain period. It can be due to Physical Water Scarcity (shortage of water due to local ecological conditions) and Economic Scarcity (due to inadequate water infrastructure). It considers three components-Water availability, Water quality and Water accessibility.

Falkenmark Water Stress Indicator

It is used to measure water scarcity. It measures scarcity in terms of renewable freshwater that is available per person per year in a country.

Conditions:

- A country is said to be experiencing water **stress** if the amount of renewable water per person per year is below 1,700 m3.
- A country is said to be experiencing a condition of **water scarcity** if the amount of renewable water per person per year is below 1,000 m3.
- A country is said to be experiencing a condition of **absolute water scarcity** if the amount of renewable water per person per year is below 500 m3.

Status of Water Stress in India

Report	Observations
The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water	80% of people living underwater stress lived in Asia; in particular, northeast China, as well as India and Pakistan.
	The global urban population facing water scarcity is projected to increase from 933 million in 2016 to 1.7-2.4 billion people in 2050, with India projected to be the most severely affected.
World Bank Study under the name "Helping India Overcome Its Water Woes"	India's per capita water availability is around 1,100 cubic meters (m3), well below the internationally recognized threshold of water stress of 1,700 m3 per person, and dangerously close to the threshold for water scarcity of 1,000 m3 per person.
Composite Water Management Index 2.0 by NITI Aayog	India is currently facing a severe water crisis, with around 820 million people residing in twelve river basins throughout the country having access to per capita water availability that is at or below 1000m3 - the recognized benchmark for water scarcity according to the Falkenmark Index.
Dynamic Ground Water Resource Assessment Report 2022	Out of the total 7089 assessment units in the country, 1006 units have been categorized as 'over-exploited'

UN-Water: Established in 2003, it is a collaborative mechanism that facilitates coordination among United Nations entities and international organizations engaged in addressing water and sanitation matters.

United Nations World Water Development Report

It is UN-Water's flagship report on water and sanitation issues. Launched on World Water Day, the report focuses on a different theme each year and gives policy recommendations to decision-makers by offering best practices and in-depth analyses. It is published by UNESCO on behalf of UN-Water. Its production is coordinated by the UNESCO World Water Assessment Programme.

World Water Day: It is held on 22 March every year since 1993. It celebrates water and raises awareness on access to safe water.

Case Studies

At Global Level

Cape town

In 2018, Cape Town faced its worst water crisis due to dwindling dam levels caused by reduced rainfall. The city was on the verge of facing a Day Zero scenario (where the taps would run dry, and water usage would be restricted to only essential services). The city averted it, by increasing water tariffs, diverting water by farmers, and implementing water-saving initiatives, such as reducing flow from showerheads and taps. These measures helped the city to overcome the crisis, serving as a lesson for sustainable water management practices.

At National Level

Chennai

In 2019, Chennai, Tamil Nadu experienced a severe water crisis, with the looming threat of a Day Zero scenario. The reasons behind the crisis were multi-fold, including the disappearing water bodies due to rampant construction activities, poor efforts in the restoration and maintenance of reservoirs and lakes, rapid urbanization, and a lack of proper planning and coordination between agencies also contributed to the crisis.

Shimla

Shimla, Himachal Pradesh has been facing regular water issues, with the first instance occurring in 2018 and another in 2022. The primary factors contributing to the crisis are a general increase in rainfall, but with shorter durations characterized by intense downpours. Moreover, the accelerated retreat of the snowline and a significant influx of tourists are also leading to shortages in water supply.

Causes of Water Stress in India

India faces a significant water stress problem, with many parts of the country experiencing water scarcity and depletion of water resources. The causes of water stress in India are complex and multifaceted, that is intensifying year by year.

- **Climate Change:** The changing climate patterns due to the combination of natural and anthropogenic factors, have led to changes in rainfall patterns. This has resulted in more extreme weather events like droughts and floods, affecting the water supply. Moreover, the intense melting of glaciers due to global warming has affected the water supply in the Himalayan region.
- **Water Pollution:** The contamination of water sources by industrial effluents, agricultural chemicals, and untreated sewage has resulted in degradation of water quality. This has made the water sources unfit for human consumption, adding to the water stress in India. As per a report by Central Pollution Control Board, cities are home to 30 percent population but contribute 70 percent to water pollution.
- **Urbanization:** Rapid and unsustainable urbanization have led to the construction of buildings, roads, and other structures, which have replaced natural surfaces with concrete surfaces that have reduced the infiltration of rainwater into the ground. This, in turn, has led to a decline in the groundwater table, affecting the availability of water. Furthermore, it also caused the vanishing of water bodies in urban areas.
- **Gap between Demand and Supply:** As the population continues to grow, the demand for water has multiplied significantly. However, the water supply has not been able to keep up. Additionally, the challenges posed by climate change and the uneven distribution of water resources throughout the country have further aggravated the issue.
- **Agricultural practices:** The agricultural sector is the largest consumer of water (around 85%) in India. Traditional irrigation methods such as flood irrigation and unregulated groundwater extraction have resulted in water depletion. Furthermore, the cultivation of water-intensive crops, encouraged by past government policies and the legacy of the Green Revolution, has made the situation worse.

Case Study-Sugarcane Crop & Water Stress in Maharashtra

Maharashtra is a major producer of sugarcane in India. The sugarcane crop is highly water-intensive, and excessive pumping of groundwater for irrigation has led to a decline in the water table. According to a report by the Maharashtra Water Resources Regulatory Authority, sugarcane cultivation consumes around 60% of the available water resources in some districts of the state, leading to water scarcity in the region. Moreover, sugarcane cultivation in Maharashtra is often characterized by poor water management practices, including flood irrigation and uncontrolled groundwater extraction. All these factors cause the drought-like situation in Maharashtra every year.

- **Industries:** The Industries require huge amounts of water from the extraction of raw materials to the distribution of products. According to estimates, industries consume around 5-8% of water in India. Thermal power plants are largest consumer of water- 87.8% of the total amount of water consumed by the industrial sector (The Energy and Resources Institute)

Drinking Water and Beverage Industries require large amounts of water for their operations, and their presence in water-scarce areas has led to the depletion of groundwater resources. A report by the Centre for Science and Environment found that many areas in India with high concentrations of beverage and packaged water plants are already facing acute water stress.

Impact of water stress

Water stress in India has multifaceted impacts on the country's economy, ecology, society, and politics. The impacts of water stress are not limited to any one sector or region, and the country faces significant challenges in managing its water resources sustainably. The impacts of water stress in India are complex and far-reaching, affecting the livelihoods and well-being of millions of people, the environment, and the country's economic and political stability.

Economic impacts:

- Water stress has a significant impact on India's economy, particularly on the agriculture and industry sectors. In 2019, India faced its worst water crisis in history, which affected over 600 million people and caused an estimated loss of $14 billion to the country's GDP (NITI Aayog, 2018).
- The industrial and commercial sectors are also affected by water stress, which leads to increased production costs and loss of business opportunities. For example, in 2018, Coca-Cola was forced to shut down its plant in Kerala due to water scarcity, resulting in a loss of $34 million (Reuters, 2018).

Ecological impacts:

- Water stress leads to environmental degradation, including the depletion of groundwater resources, reduced water availability for ecosystems, and increased pollution of water sources. For example, excessive groundwater pumping in the Ganga basin has led to a decline in groundwater levels and the drying up of surface water sources, such as the Ganga River itself (India Water Portal, 2019).
- Droughts and water scarcity also have a negative impact on biodiversity and ecosystem services, affecting the survival of wildlife and the provision of essential services such as pollination and nutrient cycling (IUCN, 2019).

Social impacts:

- Water stress disproportionately affects marginalized communities such as rural populations, women, and the poor, who are more dependent on agriculture and natural resources for their livelihoods. 63 million people in rural India lack access to clean water, and 84 million lack access to improved sanitation facilities (WaterAid India, 2020).
- Water stress also leads to conflicts and tensions between different communities, especially in areas where water resources are scarce. In 2019, violent clashes broke out in Tamil Nadu over the sharing of the Cauvery River water between Tamil Nadu and Karnataka (The Hindu, 2019).
- Women are disproportionally affected by water scarcity. A report by National Commission for Women highlighted that a rural woman in Rajasthan walks over 2.5 kilometers to reach a water source.
- As per the Study of Jal Shakti Ministry in 2022, it is estimated that the per capita water availability has declined further to 1486 cubic meters in the year 2021 from 1816 cubic meters and 1545 cubic meters in 2001 and 2011 respectively.

Political impacts:

- Water stress has significant political implications, including the potential to exacerbate existing conflicts and disputes between different states and regions. For example, the sharing of water resources between states like Karnataka, Tamil Nadu, and Andhra Pradesh has been a longstanding issue, leading to tensions and conflicts.
- Water scarcity also poses a threat to national security, as it can lead to political instability and social unrest, especially in regions with a history of conflict and insurgency. For example, in the state of Jammu and Kashmir, water scarcity has been identified as a key driver of social and political unrest (The Diplomat, 2017).

Government Initiatives to address Water Stress

Government has taken steps at multiple levels to manage the water resources efficiently and has taken all efforts to collaborate with all stakeholders to provide access to safe drinking water and address the impacts of water stress.

At National Level

- **National Water Policy:** It was introduced in 2012 to evaluate the current state of water resources in India and to suggest a framework for action with a national perspective. The policy proposed the need for a unified national water framework law and comprehensive legislation for the development of inter-state rivers and river valleys. To further revise the policy, a drafting committee has been established.
- **National Hydrology Project:** It was launched in 2016 with the aim of enhancing the quality, quantity, and availability of water resources information. It also seeks to improve the capabilities of water resources management institutions in India.
- **Atal Bhujal Yojana**

The Atal Bhujal Yojana was launched in 2019 in collaboration with the World Bank to improve groundwater management in India. It is the world's largest community-led groundwater management program.

  - It has been implemented in almost 9000-gram panchayats across seven Indian states, including Haryana, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Uttar Pradesh, and Rajasthan.
  - The aim is to ensure sustainable groundwater management by promoting the efficient use of water resources and improving participatory groundwater management practices at the community level.
- **National Project on Aquifer Management:** It was launched in 2012. It aims to map the sub-surface water-bearing geological formations in India for informed decision-making. In addition to mapping, region-wise aquifer management plans are prepared and shared with states to facilitate better management of groundwater resources.
- **Jal Shakti Abhiyaan-I:** It is a national campaign launched in 2019 by the Ministry of Jal Shakti to address the issue of water scarcity and ensure water conservation, management, and sustainable use. The major objectives are:
  - To focus on integrated demand and supply-side management of water at the local level.
  - To conserve water through the implementation of various measures like rainwater harvesting, groundwater recharge, and renovation of traditional water bodies.
  - To improve the efficiency of water use in agriculture and reduce wastage.
  - To promote better water resource governance by involving local communities, especially women, in planning and management processes.
  - To create awareness among the public about the importance of water conservation and the need to use water judiciously.

Initiatives under Jal Shakti Abhiyaan

- **Jal Shakti Kendra**: They are envisaged as water conservation hubs, which will work towards the rejuvenation of traditional water bodies, groundwater recharge, and rainwater harvesting.
- **Catch the Rain Campaign**: Launched in 2021, it covered all the blocks of all the districts across the country. The focused interventions under the program included water conservation and rainwater harvesting, reuse and recharge of bore wells, renovation of traditional and other water bodies, watershed development, and intensive afforestation.

- **Jal Jeevan Mission:** It is a flagship and mission mode project of the Indian Government, that has two components- rural and urban.
  - **Rural:** It was launched in 2019 by the Ministry of Jal Shakti of the Indian Government. It aims to ensure access to safe and adequate drinking water for every rural household in India through Functional Household Tap Connection (FHTCs) by 2024. Further, it is a movement to create a "Jan Andolan" for water. It seeks to engage the entire community in the planning, implementation, and management of water supply systems, making water everyone's priority.
  - **Urban:** It was launched under the Union Budget 2021-22 under the Ministry of Housing and Urban Affairs. It aims to provide universal coverage of water supply to all households through functional taps in all statutory towns in accordance with Sustainable Development Goal-6. Apart from it, other objectives are securing tap and sewer connections, Rejuvenation of water bodies, and creating a circular water economy.
- **Interlinking of Rivers:** The Indian government has announced several major river interlinking projects. One of these is the Ken-Betwa Link Project, with an estimated cost of Rs 44,605 crore, which was announced in the 2022-23 budget. In addition, draft Detailed Project Reports have been finalized for five river links, including Damanganga-Pinjal, Par-Tapi-Narmada, Godavari-Krishna, Krishna-Pennar,

and Pennar-Cauvery. These projects aim to improve water management and availability in various regions of the country.

- **Central Ground Water Board:** It was established in 1970 by renaming the Exploratory Tube Wells Organization. Its objective is to promote sustainable development and management of Ground Water Resources in India. The **Central Ground Water Authority (CGWA)** was constituted under the Environment (Protection) Act, of 1986 for the regulation and control of groundwater development and management in the country. Together, the CGWB and CGWA play a crucial role in the management and regulation of groundwater resources in India.
- **Composite Water Management Index:** It is a tool developed by the NITI Aayog to assess and improve the performance of states in the efficient management of water resources.
  - It takes into account various indicators such as groundwater restoration, major and medium irrigation, watershed development, participatory irrigation practices, and policy and governance.
  - The index aims to create awareness and provide information for sustainable water resource management, conservation, and utilization.
  - By ranking states based on their performance, encourages healthy competition and motivates them to take necessary steps for efficient water management, thereby helping to conserve water.
  - In 2019, NITI Aayog released Composite Water Management Index 2.0 to rank various states for their performance in better management of water resources (2017-18 as the reference year and 2016-17 as the base year). Gujarat had topped the index.
- **Mission Amrit Sarovar:** Launched in 2022, it aims at developing and rejuvenating 75 water bodies in each district of the country as a part of the celebration of Azadi ka Amrit Mahotsav.

Environmental Impact of Interlinking of Rivers

- **Alteration of River Ecosystems**: The interlinking of rivers can lead to significant changes in natural river ecosystems. The diversion of water disrupts the flow patterns, resulting in altered water availability, quality, and speed. This disruption can have adverse effects on aquatic habitats and biodiversity. The loss of habitat for various plant and animal species can disrupt their survival and the delicate balance of ecosystems.
- **Deforestation and Habitat Loss**: The construction of canals and dams required for river interlinking often involves land clearance, leading to deforestation. Deforestation results in the loss of valuable forest ecosystems, biodiversity, and carbon sequestration capacity. It also fragments natural habitats and disrupts the interconnectedness of ecosystems. Wetlands, which play crucial roles in water filtration, flood control, and providing habitat, may be lost or severely impacted.
- **Disruption of Natural Water Flow**: Interlinking alters the natural hydrological cycle of river basins. Changes in water availability, distribution, and flow patterns can have far-reaching consequences. The downstream ecosystems and communities dependent on the natural water flow can be significantly affected. There is also a risk of exacerbating floods or droughts in certain regions, further disrupting the natural balance.
- **Climate Change Implications**: The interlinking of rivers can have implications for climate change. Deforestation associated with the construction of canals and dams reduces the capacity to sequester carbon dioxide. The loss of wetlands decreases natural water storage and filtration capacity, impacting local and regional water cycles. Disrupted ecosystems can also contribute to greenhouse gas emissions and affect climate patterns, creating potential feedback loops.
- **Water Pollution:** Interconnecting rivers can facilitate the spread of pollutants from one basin to another. Industrial and agricultural runoff, as well as sewage discharge, can contaminate previously clean water sources. The increased flow of water can exacerbate pollution problems, leading to degraded water quality and posing risks to human and aquatic life. This pollution can have long-term impacts on the health and sustainability of river ecosystems.

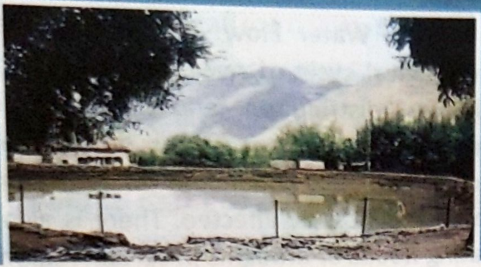
At State Level

- **Paani Bachao, Paisa Kamao**: Launched by Punjab government, it aims to encourage farmers to make judicious use of electricity. They are incentivized for every unit of electricity they saved. This will indirectly reduce the unnecessary exploitation of groundwater in agriculture.
- **Mera Paani Meri Virasat:** Launched by Haryana Government, under this scheme, the government provides incentives (Rs 7000 per acre) to the farmers to cultivate alternative crops which are less water-intensive.
- **Namma Ooru-Namma Veetu' (Our town, our house):** Launched by Tamil Nadu government, it aims to encourage households to adopt rainwater harvesting and offered financial incentives to those who installed the system.

DO YOU KNOW?

World Water Day is an annual event observed on **March 22nd**. It aims to raise awareness about the importance of freshwater and the need for sustainable management of water resources. The day was first designated by the United Nations General Assembly in 1993.

Traditional Methods of Water Conservation



Kul

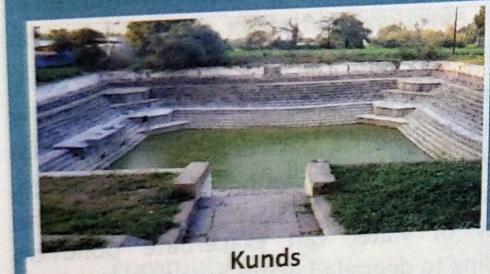
These are man-made channels found in the Jammu region and Spiti Valley of Himachal Pradesh. They divert water from streams and rivers to irrigate agricultural fields and are maintained collectively by communities.

Khatri

It is practised in Kangra, Mandi, and Hamirpur districts of Himachal Pradesh. They are structures carved into the hard mountain and collect rainwater through seepage for human consumption and through pipes for animals and washing.

Apatani System

It is practised by the Apatani Tribe in the Subansari district of Arunachal Pradesh. It involves terracing the valleys into plots and dividing them with earthen dams supported by bamboo frames, which regulate the flow of water between the plots.

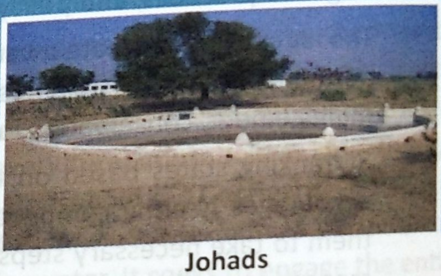


Kunds

It can be found in the Thar Desert of Western Rajasthan and some parts of Gujarat. Wells are constructed with a saucer-shaped catchment area that slopes towards the centre. The sides of the well pit are covered with lime and ash to prevent contamination of the

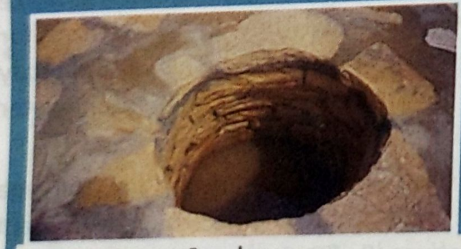
Baoris/Bers

These are community wells found in Rajasthan, originally built by the Banjara community for their own water needs. They are designed to minimize water evaporation and are mainly used for drinking water, allowing collected water to remain stored for a long time.



Johads

These are small earthen check dams found in the central highlands. They are designed to capture and conserve rainwater, improve percolation and recharge of groundwater, prevent soil erosion, and promote the growth of vegetation in the area.



Sazakuva

Found In the Aravalli hills of Mewar, Rajasthan, it is an open well with multiple owners and serves as an important source of irrigation. It features an elevated platform sloping away from the well, built from soil excavated during its construction.

Ramtek Model

Found in Ramtek town of Maharashtra, the model uses an intricate network of groundwater and surface water bodies connected through canals to harvest runoff through tanks. The model is supported by high-yielding wells, baoris, kunds, and waterholes.

Nadis Jhalaras

These are rectangular tanks found in Rajasthan and Gujarat, built for community use and religious purposes. They have stepped on three or four sides for easy access and are designed to store water from natural catchment areas during the rainy season.

Traditional Methods of Water Conservation

Best Practices

At Global Level: NEWater Project, Singapore:

It was launched in 2002 and is a highly advanced water recycling program that involves putting treated used water through dual-membrane (microfiltration and reverse osmosis) and ultraviolet technologies. The resultant water exceeds WHO drinking water standards.

At National Level: Mukhya Mantri Jal Swavlambhan Abhiyan:

It is a participatory water management program launched by Rajasthan Government in 2016. It involves multiple stakeholders and aims to make villages self-sufficient in water. The program also uses drones to identify water bodies for restoration. The first phase of the program saw a 56 percent reduction in water supply through tankers, an average rise in the groundwater table by 4.66 feet in 21 non-desert districts, 50,000 hectares of additional land made fit for cultivation, and rejuvenation of 64 percent of installed hand-pumps.

LIGHT POLLUTION

LIGHT POLLUTION

Light Pollution is the alteration of night natural lighting level caused by unwanted, inappropriate or excessive anthropogenic artificial sources of light. It's a side effect of industrial civilization and urbanization.

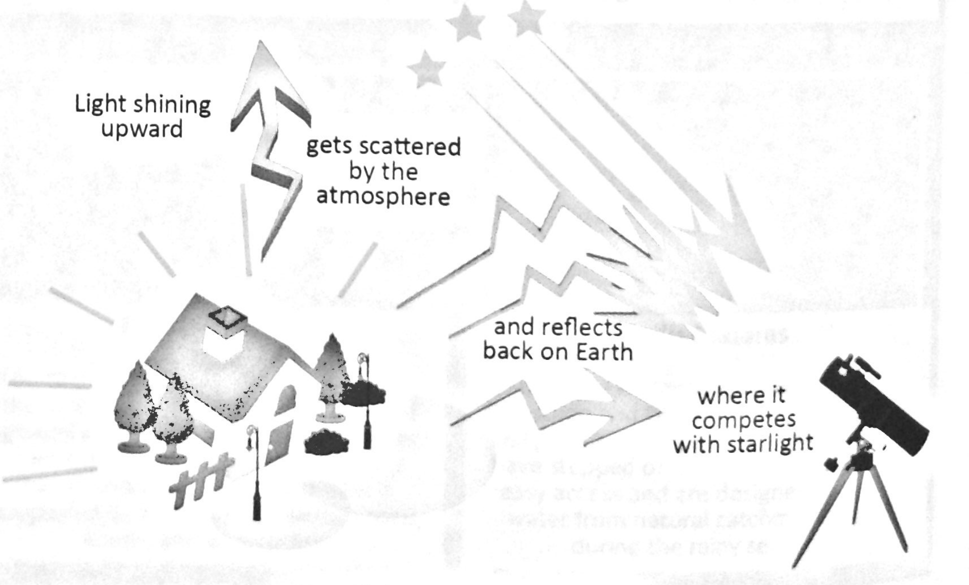
Sources of Light Pollution

Sources of light pollution include exterior and interior lighting, advertising, outdoor area lighting (such as car parks), offices, factories, streetlights and illuminated sporting venues.

- **Outdoor Lighting:** Outdoor lighting is the primary source of light pollution. Streetlights, security lights, and other types of outdoor lighting are often designed to be bright and can emit light in all directions, including upward. This causes light to scatter in the atmosphere and creates a glow in the night sky.
- **Commercial Lighting:** Commercial buildings such as shopping malls, gas stations, and stadiums often use large amounts of outdoor lighting to illuminate their premises. These lights can be very bright and often run all night, contributing to light pollution.
- **Residential Lighting:** Many homeowners use outdoor lighting to illuminate their property, such as porch lights, floodlights, and garden lights. While these lights can be useful for safety and security, they can also contribute to light pollution if they are too bright or not properly shielded.
- **Industrial Lighting:** Factories, warehouses, and other industrial facilities often use bright outdoor lighting to illuminate their premises. These lights can be visible from long distances and contribute to light pollution.
- **Advertising Lighting:** Billboards and other types of advertising often use bright, colorful lights to attract attention. These lights can be very bright and contribute to light pollution, especially in urban areas.
- **Vehicle Lighting:** The headlights, taillights, and other types of lighting on cars, trucks, and buses can contribute to light pollution, especially on busy roads and highways.
- **Astronomical Observatories:** Astronomical observatories and research facilities often require dark skies to conduct their research. Light pollution from nearby cities and towns can interfere with their observations and make it difficult to study the stars and planets.

Types of Light Pollution

- **Sky Glow:** It is the bright halo that appears over urban areas at night, a product of light being scattered by water droplets or particles in the air. It is the most prevalent form of light pollution
- **Glare:** It is the excessive brightness that can cause visual discomfort. (Example: while driving)
- **Light Trespass:** It is when light extends into an rea where it is not wanted or needed (like a streetlight


Light shining upward
gets scattered by the atmosphere
and reflects back on Earth
where it competes with starlight

How Light Create Light Pollution

illuminating a nearby bedroom window)

- **Clutter:** It is bright, confusing and excessive groupings of light sources (For example: Times Square in New York City).

Impact of Light Pollution

- **Human health:** Light pollution may cause various health issues to our body such as irritation in eyes, redness in eyes and some severe cases permanent darkness in eyes, etc. Excess light may also cause headaches, fatigue, stress, and anxiety in many people who are quite often exposed to over-illumination.
- **Environmental impacts:**
    - **Impact on nocturnal wildlife:** Light pollution radically alters the nighttime environment by turning night into day, which will have negative impact on physiology, breeding patterns and mating behaviors of nocturnal animals.
    - **Disrupting ecosystems:** Artificial light can disrupt the natural rhythms of wildlife, such as birds, insects, and sea turtles. This can make it difficult for them to navigate, feed, and reproduce, which can have a ripple effect on entire ecosystems.
    - **Disturbing migratory patterns:** Birds, butterflies, and other animals rely on the stars and moonlight to navigate during migration. Artificial light can disorient and confuse these animals, making it difficult for them to reach their destination.
    - **Insect biodiversity loss:** Artificial light alters the patterns of insect movement, foraging, reproduction and predation of insects resulting in the decline of insect population.
    - **Carbon footprint:** In the U.S. alone, about 15 million tons of CO2 are emitted each year to power residential outdoor lighting that equals the emissions of about 3 million passenger cars and adds up to 40,000 tons per day.
- **Economic impacts:** Light pollution can have a significant impact on the economy by reducing visibility, hindering astronomical research, and diminishing the value of dark skies for tourism and recreation.
- **Impacts on astronomical observations:** Light pollution is one of the main factors that affect astronomical observations, which makes it difficult to see celestial objects from the ground.
- **Energy consumption:** Light pollution contributes to energy waste, as much of the light is directed upwards and not towards the intended targets.

Global initiatives to curb light pollution

- **The International Year of Light and Light-based Technologies (IYL 2015):** It was by the United Nations to raise awareness of the importance of **light and optical technologies** in our daily lives, and to encourage the responsible use of artificial light to reduce light pollution.
- **International Dark-Sky Association (IDA):** The IDA is a non-profit organization that works to protect the night sky from light pollution. It provides guidelines and recommendations for outdoor lighting that minimize the amount of light pollution while still providing adequate illumination for safety and security.
- **Globe at Night:** Globe at Night is a citizen science program that encourages people around the world to measure and report the amount of light pollution in their area. The data collected through this program is used to create maps of light pollution around the world and to raise awareness about the issue.
- **International Astronomical Union (IAU):** The IAU is an organization of professional astronomers that works to promote and protect astronomy and the night sky. It has developed guidelines for outdoor lighting that minimize light pollution and ensure that astronomical observations can be conducted effectively.
- **International Dark Sky Places (IDSP):** The IDSP program recognizes places around the world that have taken steps to protect their dark skies. These places are designated as Dark Sky Parks, Dark Sky Reserves, or Dark Sky Communities, depending on the level of protection and preservation of the night sky.
- **World Heritage Sites:** Several UNESCO World Heritage Sites have been designated as Dark Sky Parks or Reserves, including the Grand Canyon National Park in the United States and the Aoraki Mackenzie International Dark Sky Reserve in New Zealand. These designations recognize the importance of protecting the night sky as part of our cultural and natural heritage.

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NOISE POLLUTION

NOISE POLLUTION

Noise is an unpleasant and unwanted sound that is loud and disruptive to hearing. Noise pollution is unpleasant noise created by people or machines that is annoying, distracting, intrusive, and/or physically painful. According to the UNEP Annual Frontier Report 2022, Dhaka has been identified as the world's most noisy city, closely followed by Moradabad in Uttar Pradesh. Among the noisiest cities globally, five Indian cities have been listed, including Asansol, Jaipur, Kolkata, New Delhi, and Moradabad.

The World Health Organization (WHO) states that approximately 1.1 billion young people, aged between 12 and 35 years, are in danger of experiencing hearing loss due to prolonged exposure to high levels of noise.

Major Sources of Noise Pollution

- **Traffic:** Road traffic, including vehicles such as cars, motorcycles, trucks, and buses, generate significant noise pollution, especially during peak hours or in urban areas with heavy traffic congestion.
- **Construction and Industrial Activities:** Construction sites, factories, and industrial facilities produce high levels of noise due to machinery, equipment, and heavy operations. Activities like drilling, hammering, grinding, and heavy machinery operation contribute to noise pollution.
- **Airports and Aircraft:** Airports and aircraft produce substantial noise, particularly during takeoff and landing. The noise from jet engines and the sonic boom created by supersonic flights cause significant noise pollution in areas near airports.
- **Railways:** Trains running on railway tracks generate considerable noise, especially when passing through residential areas or during the operation of heavy freight trains. The noise is caused by the wheels on the tracks, engine noise, and the sound of the horn.
- **Neighbourhood Noise:** Various activities within residential areas contribute to noise pollution. These include loud music, parties, barking dogs, lawn mowers, power tools, and other household appliances.
- **Commercial Establishments:** Restaurants, bars, clubs, and entertainment venues often generate noise pollution due to music, conversations, and other activities. The noise impact nearby residents and disturb their peace and quiet.
- **Construction of Public Infrastructure:** Building projects for public infrastructure like roads, bridges, and tunnels create noise pollution due to construction machinery, pile drivers, and other heavy equipment used in the process.
- **Public Transportation:** Public transportation systems such as buses, trams, and subway trains generate noise pollution from engine noise, brakes, and the movement of the vehicles.
- **Emergency Services:** Sirens from police cars, fire trucks, and ambulances cause noise pollution, although they are essential for public safety.

Impact of Noise Pollution

Impact of noise pollution on health:

Exposure to noise pollution can have detrimental effects on human health. Here are some impacts of noise pollution on health:

- **Hypertension:** Prolonged exposure to high levels of noise can lead to increased blood pressure, potentially causing hypertension in individuals.
- **Hearing Impairment:** Continuous exposure to excessive noise levels that surpass the normal range of sound intensity damage the eardrums, leading to hearing disabilities.
- **Sleep Disturbances:** Noise pollution disrupt the sleep cycle, leading to sleep disorders, decreased energy levels, and fatigue in affected individuals.

- **Cardiovascular Problems:** Loud noises elevate blood pressure levels beyond the norm and contribute to various cardiovascular diseases among otherwise healthy individuals.

Impact of noise pollution on animals and birds:

Noise pollution has adverse effects on animals and birds, disrupting their natural behaviour, communication, and overall well-being. Here are some impacts of noise pollution on animals and birds:

- **Communication Interference:** Loud noises interfere with animal and bird communication systems. Many species rely on vocalizations to communicate with mates, offspring, and members of their social group. Excessive noise mask these vital communication signals, making it difficult for animals to locate mates, defend territories, or coordinate group activities.
- **Disruption of Reproduction and Breeding:** Noise pollution disturb the reproductive behaviour of animals and birds. Loud noises mask mating calls or disrupt courtship displays, leading to a decline in successful reproduction. This has long-term impacts on population numbers and genetic diversity.
- **Habitat Abandonment:** Animals and birds may abandon their natural habitats or breeding areas due to high levels of noise pollution. Areas with constant noise disturbance become less suitable for nesting, feeding, and raising offspring, forcing them to seek alternative habitats, which may not provide the necessary resources for survival.
- **Changes in Foraging Patterns:** Noise pollution alter the foraging patterns of animals and birds. Loud noises startle or frighten them, causing them to abandon feeding areas or interrupt their search for food. This disruption result in reduced food intake, impacting individual fitness and overall ecosystem dynamics.
- **Physiological Stress:** Continuous exposure to noise cause chronic stress in animals and birds. Stress hormones, such as cortisol, may increase, affecting their immune system, reproductive health, and overall physiological well-being. Prolonged stress lead to reduced growth rates, weakened immune responses, and increased susceptibility to diseases.
- **Masking of Auditory Cues:** Animals and birds rely on their acute hearing to detect vital auditory cues from their environment, such as approaching predators, prey, or environmental changes. Noise pollution mask these important cues, making it difficult for them to detect potential threats or changes in their surroundings, compromising their survival instincts.
- **Impact on Migration Patterns:** Noise pollution along migratory routes disrupt the natural navigation and orientation abilities of birds and animals. They may become disoriented, leading to deviations from their regular migration paths, which result in population fragmentation and loss of critical habitats.
- **Disturbance of Nocturnal Species:** Nocturnal animals and birds that rely on the darkness and quiet of the night for essential activities, such as hunting or foraging, be significantly affected by artificial noise sources. Bright lights and loud noises disrupt their natural behavior and have cascading effects on their feeding patterns, reproduction, and overall ecological interactions.

Ocean Noise Pollution

Ocean noise refers to **sounds made by human activities** that can interfere with or obscure the ability of marine animals to hear natural sounds in the ocean.

- **Sources of ocean noise pollution:**

The main sources are human activities such as shipping, oil and gas exploration and production, construction, and naval sonar.

  - **Other sources** include commercial and recreational fishing, and underwater blasting.
  - **Climate change** also contributes to ocean noise pollution through the melting of sea ice and the increased frequency of storms.

- **Impacts of ocean noise pollution:**
  - **Threat to marine life:** Increased levels of underwater noise emission endanger the lives of marine mammals, whose essential behavioural activities rely on sound as the main form of energy.
  - **Masking of important sounds:** Ships' noise and vibrations in the low-frequency range (<500 Hz) can mask marine species' communication frequencies, potentially altering migration routes and impeding their return to deeper waters.
  - **Long-term effects:** The sound that radiates from ships on a long-term basis affects them and results in internal injuries, loss of hearing ability, change in behavioural responses, masking, and stress.

Control of Noise Pollution in India

- **Noise Pollution (Regulation and Control) Rules, 2000:** It prohibits the use of loudspeakers at night and provide provisions for penalties in case permission for the use of such devices is not sought from a competent authority.

- **Permissible level of noises:** The Central Pollution Control Board (CPCB) in India has established regulations concerning noise levels in different areas, with the following guidelines:
- **Acceptable Noise Levels:** The defined rules specify the permissible noise levels for various areas during different times. Daytime is categorized as 6 am to 10 pm, and nighttime is considered from 10 pm to 6 am.
- **Industrial Areas:** In industrial areas, the acceptable noise limit is set at 75 dB during the daytime and 70 dB during the night. This ensures a controlled level of noise pollution in these regions.
- **Commercial Areas:** For commercial areas, the permissible noise levels are lower compared to industrial areas. During the daytime, the limit is set at 65 dB, while during the night, it is further reduced to 55 dB.
- **Residential Areas:** The regulations define even lower noise limits for residential areas to ensure a peaceful living environment. In residential areas, the acceptable noise level during the daytime is 55 dB, and during the night, it is further reduced to 45 dB.
- Noise standards for motor vehicles, air-conditioners, refrigerators, diesel generators and certain types of construction equipment are prescribed under the Environment (Protection) Rules, 1986.
- Noise emanating from industry is regulated by State Pollution Control Boards / Pollution Control Committees (SPCBs / PCCs) for states / Union territories under the Air (Prevention and Control of Pollution) Act, 1981.
- In 2005, the Supreme Court held that **freedom from noise pollution is a part of the right to life under Article 21 of the Constitution.**

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RADIOACTIVE POLLUTION

RADIOACTIVE POLLUTION

Living organisms are continuously exposed to a variety of radiations called background radiations. When the level of the radioactive radiations becomes harmful and poses a significant threat to living organisms and the environment, it is called radioactive pollution. Instances of Radioactive Pollution could be found in Chernobyl Disaster in USSR, 1986, 'Three Mile Island' plant in Middletown (U.S.A.), 1979, Fukushima Nuclear Disaster in Japan, 2011 and Mayapuri radiological accident, Delhi, India, 2010 (People were exposed to cobalt-60, a radioactive element).

Sources of Radiation

Natural Sources:

- **Cosmic Radiation:** It consists of fast-moving particles that exist in space. It originates from a variety of sources, including the sun and other celestial events in the universe. Some of this radiation penetrates the earth's atmosphere and is absorbed by living organisms.
- **Terrestrial Radiation:** The main contributors are natural deposits of **uranium, potassium and thorium**. These, in the process of natural decay, release small amounts of ionizing radiation.
    - Naturally occurring radioisotopes such as **radon-222** found in soil in small quantity is another source of radioactive radiations.

Anthropogenic Sources:

- **Diagnostic medical applications**: The use of radioactive isotopes in diagnostic tests and treatments such as X-rays, nuclear medicine, can lead to the release of radioactive materials into the environment if not properly managed.
- **Industrial Sources**: improper disposal or incineration of devices which contain radioactive isotopes, such as nuclear gauges and smoke detectors, can release radioactive substances into the environment
- **Atmospheric testing:** The atmospheric testing of atomic weapons from the end of the World War II until as late as 1980 released radioactive material, called **fallout**, into the air.
- **Nuclear fuel cycle**: nuclear power plants, uranium mines, fuel fabrication plants and radioactive waste facilities release regulated levels of radioactive materials.

Ionizing and Non-Ionizing Radiation

Ionizing Radiation	Non-Ionizing Radiation
It refers to high-energy radiation	It refers to low-energy radiation
It has enough energy to remove tightly bound electrons from atoms or molecules, resulting in the formation of ions.	It does not have enough energy to ionize atoms or molecules.
Types: Alpha particles, beta particles, gamma rays, X-rays, and certain types of ultraviolet (UV) radiation. *Gamma penetrates most; alpha penetrates the least.	**Types:** Radio waves, microwaves, infrared radiation, visible light, and certain types of ultraviolet (UV) radiation.
Sources: Cosmic rays, radon gas, radioactive materials, nuclear power plants, radioactive materials used in medical diagnostic devices.	**Sources**: Sunlight, Mobile phones, Wi-Fi routers, microwave ovens, power lines, mobile phone towers, etc.
More harmful	Less harmful

Impact of Radioactive Pollution

- **Impact on Health**
  - **Increased risk of cancer:** Exposure to high levels of radiation can damage DNA. This eventually increases the likelihood of developing various types of cancer.
  - **Genetic disorders**: Radioactive pollution can cause mutations in reproductive cells and may lead to hereditary genetic disorders in future generations.
  - **Acute radiation sickness**: High doses of radiation can lead to nausea, fatigue, organ damage, and even death.
- **Impact on Environment**
  - **Ecological imbalance:** Radioactive pollution can disrupt ecosystems, affecting plants, animals, and microorganisms, and altering the balance of populations.
  - **Soil and water contamination**: Radioactive materials can contaminate soil and make soil infertile. It also contaminates water bodies. Soil and water contamination finally leads to long-term environmental degradation and the bioaccumulation of radioactive substances in the food chain.
  - **Decreased biodiversity:** Exposure to radiation leads to reduced biodiversity in affected areas. For example, after Chernobyl Disaster, it was found that bird populations in the area, including barn swallows and great tits, experienced decreased numbers and reproductive success.

Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management

It is an International Atomic Energy Agency (IAEA) treaty which was adopted in 1997 and entered into force in 2001. It seeks to address radioactive waste management on a global scale. Currently, there are 71 state parties. India is not a party to the Convention.

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MINING POLLUTION

MINING POLLUTION

Mining pollution refers to the environmental impact of mining activities, which can release a variety of toxic substances into the air, water, and soil. The key impact of mining pollution is on wildlife and aquatic habitats, the river system, local climate & pattern of rainfall, sedimentation, depletion of forest & disruption of ecology.

Common pollutants associated with mining

- **Heavy metals:** Mining can release heavy metals such as lead, arsenic, and mercury, which can accumulate in the soil, water, and food chain and cause serious health problems for humans and wildlife.
- **Acid mine drainage:** Acid mine drainage occurs when water comes into contact with rocks that contain sulphide minerals, which can create sulfuric acid. This acidic water can then leach heavy metals and other toxic substances from the surrounding rock, contaminating nearby water sources.
- **Tailings:** Tailings are the waste materials left over after the extraction of valuable minerals from the ore. These tailings can contain high levels of heavy metals and other toxic substances, and if they are not properly managed, they can contaminate nearby water sources and soil.
- **Dust and particulate matter:** Mining activities can generate large amounts of dust and particulate matter, which can cause respiratory problems for people and wildlife in the surrounding areas.
- **Land disturbance:** Mining activities can also result in the removal of vegetation and topsoil, which can have negative impacts on local ecosystems and wildlife habitats

Effects Of Mining Pollution on Environment

- **Water pollution:** Mining activities can release a variety of toxic substances into nearby water sources, contaminating rivers, lakes, and groundwater supplies. These pollutants can harm aquatic ecosystems as it reduces the percentage of dissolved oxygen and makes it unsafe for humans and animals to drink the water as biomagnification takes place.
- **Soil pollution:** Mining can disturb large areas of land, removing vegetation and topsoil and leaving behind barren landscapes. This can lead to soil erosion and contamination, making it difficult for plants to grow and disrupting ecosystems.
- **Air pollution**: Mining activities can release dust and particulate matter into the air, which can cause respiratory problems for people and wildlife in the surrounding areas. Mining can also release greenhouse gases and other pollutants, contributing to climate change and other environmental problems.
- **Biodiversity loss:** Mining can disrupt ecosystems and wildlife habitats, leading to a loss of biodiversity and the extinction of certain species.
- **Land use:** Mining activities often require large amounts of land, which can have negative impacts on local communities and wildlife habitats. Mining can also lead to the displacement of indigenous peoples and other communities that rely on the land for their livelihoods.
- **Waste disposal:** Mining activities generate large amounts of waste, including tailings (the waste materials left over after the extraction of valuable minerals from the ore), which can contain high levels of heavy metals and other toxic substances. If these waste materials are not properly managed, they can contaminate nearby water sources and soil.

Legislative Measures to Combat Mining Pollution

In India, mining pollution is regulated by several laws and regulations at the national and state levels. Some of the key legislations related to mining pollution in India are:

- **The Mines and Minerals (Development and Regulation) Act, 1957**: This is the primary legislation that governs the regulation of mines and minerals in India. The act empowers the central and state governments to regulate and control the exploration, development, and management of mineral resources in the country.
- **The Environmental Impact Assessment (EIA) Notification, 2006:** This is a notification issued by the Ministry of Environment, Forest and Climate Change that requires all mining projects to undergo an environmental impact assessment and obtain clearance from the regulatory authorities before commencing operations.
- **The Water (Prevention and Control of Pollution) Act, 1974:** This act regulates the discharge of pollutants into water bodies and requires mining companies to obtain consent from the state pollution control board before discharging any pollutants into water bodies.
- **The Air (Prevention and Control of Pollution) Act, 1981:** This act regulates the emission of pollutants into the air and requires mining companies to obtain consent from the state pollution control board before emitting any pollutants into the air.
- **The Forest (Conservation) Act, 1980:** This act regulates the diversion of forest land for non-forest purposes, including mining, and requires mining companies to obtain clearance from the central government before diverting any forest land.
- **The National Mineral Policy, 2019:** This policy provides guidelines for the sustainable development of the mining sector in India and emphasizes the need for environmental and social safeguards.

"Go" and "No- GO" Zones in Coal Mining

- **Background:** In 2009, the Coal Ministry and the Environment Ministry introduced the concept of "Go and No-Go" zones for coal mining. This approach involves the identification of areas based on their ecological and environmental value to determine whether they are suitable or unsuitable for coal mining.
- **"GO" Zones:** In the "Go" zones, coal mining can be permitted after implementing appropriate measures to mitigate environmental impact.
- **"No- GO" Zones:** In the "No-Go" zones are areas where coal mining is prohibited due to their ecological and environmental significance. To determine the No-Go zones, various factors such as forest cover, wildlife habitats, and water bodies are taken into consideration.
- **Significance:** The approach seeks to strike a balance between the need for coal mining and the preservation of the environment and biodiversity. It aims to minimize the environmental consequences associated with coal mining and promote the principles of sustainable development.

Case Study: Kolar Gold Fields

An example of effective utilization of mining waste in India is the case of the Kolar Gold Fields in Karnataka, where a pilot project was launched to extract gold from the mining waste using biotechnology

In 2017, the Council of Scientific and Industrial Research (CSIR) launched a pilot project to extract gold from the mining waste using a biotechnological process called bioleaching. Bioleaching involves the use of bacteria to dissolve metals from ores and concentrates.

The CSIR developed a process using a consortium of bacteria to extract gold from the mining waste. The process involved the use of a bioreactor to treat the waste with the bacteria, which dissolved the gold and other metals in the waste. The dissolved metals were then recovered using standard chemical methods. The pilot project was successful, with the bioleaching process recovering around 20-25% of the gold from the mining waste.

SAND MINING

Sand mining is the extraction of sand from beaches, rivers, seabeds, and other natural environments. It is often done to meet the demands of construction and infrastructure development, such as for making concrete, as well as for industrial purposes like glassmaking and electronics manufacturing.

According to the Indian Bureau of Mines, the total resources of sand in India are estimated to be around 28.5 billion cubic meters. This includes both beach sand and river sand

Types of Sand

- **River Sand:** Sand derived from river channels, estuaries, deltas, and river floodplains
- **Lacustrine Sand:** Sand sourced from lakes.
- **Marine Sand:** Sand derived from near- and offshore deposits, beaches, bays, and lagoons
- **Manufactured Sand (M-Sand):** Artificial sand, produced by crushing large hard stone like granite into sand-sized aggregate particles. Generally, the size of M-Sand is less than 4.75mm.
- **Sub-types:**
  - **Ore-sand (O-sand):** Processed sand sourced as a co-product or by-product of mineral ores.

» **Crushed Rock Sand:** Manufactured by crushing the rocks like granite, limestone, sandstone etc.

Impact of Sand Mining on Environment

Sand mining can have a range of negative environmental effects, including:

- **Habitat destruction:** Sand mining can destroy habitats for fish, birds, and other wildlife. When sand is extracted from riverbeds or coastlines, it can alter the natural flow of water and cause changes in the landscape, leading to habitat loss and fragmentation.
- **Water quality degradation**: Sand mining can cause sedimentation and siltation in water bodies, which can reduce water quality and harm aquatic life. Sedimentation can also affect the ability of water bodies to store and convey water, leading to flooding and other water-related hazards.
- **Salinity:** Sand in the river is extracted which leads to deepening of estuaries & rivers which lead to enlargement of river mouths, which in turns leads to saline water intrusion.
- Sand mining can lead to soil erosion, particularly when it is carried out on hillsides or other sloping terrain. This can lead to increased runoff and the loss of fertile topsoil.
- **River Erosion:** The extraction of sand affects the course of the river, which leads to variation in course of the river leading to river erosion along sides and floods during monsoon and coastal erosion.
- **Fishing industry:** The rampant sand mining is leading to ecological imbalance which is affecting aquatic life and thus decreasing the catching of fishes which affects the fishing industry.
- **Air and noise pollution:** The use of heavy machinery in sand mining can generate dust and noise, which can affect the health and well-being of nearby communities and wildlife.
- **Landscape Destruction:** Sand mining can alter the natural flow of rivers and streams, leading to changes in the landscape and the loss of natural habitats due to removal of vegetation cover, which can cause soil erosion and reduce the ability of the landscape to hold water, which can alter the topography.
- **Social impacts:** Sand mining can also have social impacts, such as the displacement of local communities, loss of access to traditional resources, and conflict over resource use.

Regulation of Sand in India

- It is classified as a **minor mineral** under the **Mines and Minerals (Development and Regulations) Act, 1957 (MMDR Act). The State governments** are vested with the administrative control over minor mineral.
- In 2016, Ministry of Environment, Forest and Climate Change (MoEFCC) issued **Sustainable Sand Mining Management Guidelines, 2016** to address issues related to regulation of sand mining and promote sustainable sand management.
- In 2020, MoEFCC issued **Enforcement and Monitoring Guidelines for Sand Mining 2020** to address illegal sand mining.

- **Chambal River sand mining case:** In 2017, the Supreme Court of India banned sand mining in the Chambal River in Madhya Pradesh, citing the ecological damage caused by the activity.
- **Yamuna River sand mining case**: In 2019 in case of Anil Kumar, Delhi Jal Board V/s Govt. of NCT of Delhi, the National Green Tribunal (NGT) ordered a ban on sand mining in the Yamuna River in Uttar Pradesh and imposed a fine of Rs. 50 crore on the state government for failing to take action against illegal mining & reinstated the concept of polluters pay principle.
- **Kerala flood and sand mining case:** In 2018, devastating floods in Kerala were attributed in part to unregulated sand mining in riverbeds and coastal areas. Following the disaster, the state government cracked down on illegal mining and implemented new regulations to control the activity.

Previous Year Questions (Prelims)

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TRACKING ENVIRONMENTAL ISSUES IN INDIA

ENVIRONMENT PROTECTION ACT 1986

The Environment (Protection) Act was enacted in 1986 with the objective of providing for the protection and improvement of the environment. It empowers the government to control and prevent pollution, regulate hazardous substances, and establish boards to control pollution. It plays a crucial role in ensuring sustainable development and addressing environmental issues in India.

Why was it Introduced?

It was introduced to fulfill various needs and commitments of India, including

- **Growing Environmental Concerns:** During the 1980s, several issues such as water and air pollution, deforestation, industrial waste, and degradation of natural resources were becoming threats to the Indian environment. To cope with them, comprehensive legislation was needed.
- **International Commitments:** India was a signatory to several international conventions and agreements related to environmental protection. The enactment of this act was a step towards fulfilling India's obligation. For example: -the United Nations Conference on the Human Environment which was held in Stockholm in 1972.
- **Legal Framework:** Before the EPA, India had fragmented and scattered environmental laws. There was a vacuum for a comprehensive framework to combat environmental issues effectively. This new act aimed to consolidate and strengthen all the existing laws and provided a unified framework for environmental preservation.
- **Public Awareness and Activism:** There was a growing public awareness and concern for environmental issues in India in the 1980s. Environmental activists, organizations, and other citizen groups played an important role in voicing out environmental problems and demanding stronger legislation. In response to these voices, Government came up with a new law.
- **Industrial Growth and Pollution:** India saw a rapid growth of industries in the 1980s, which caused several issues such as unsustainable urbanization, increased pollution, and environmental degradation. The new act brought to bring strict regulations on industrial activities and protect environment.

Key Provisions of EPA

Some of the key provisions of the act are:

- **Regulation of Environmental Pollution:** The act allows pollution control boards to define standards for the discharge and emission of pollutants into air, water, and land. It makes it mandatory for people and industries to comply with the standards and obtain necessary permits
- **Hazardous Substances Management:** It regulates the handling, storage, transportation, and disposal of hazardous substances. It further requires industries that deal with hazardous substances to take appropriate actions to check accidents and minimize the impact on humans and the environment.
- **Environmental Impact Assessment (EIA):** It provides for conducting Environmental Impact Assessments for certain projects that can have adverse impacts on the environment. The EIA process ensures that expected environmental consequences are considered and mitigated before granting project clearance.
- **Powers of Entry, Inspection, and Sampling:** It allows authorized officers and pollution control boards to inspect the equipment, and take samples to ensure compliance with environmental regulations.
- **Offenses and Penalties:** The act defines various environmental offenses related to pollution, non-compliance with regulations, etc. It prescribes penalties, fines, and imprisonment, for these offenses, depending on their severity.

- **Public Participation and Awareness:** It encourages public awareness and participation in environmental decision-making processes. It mandates the disclosure of information related to different environmental issues to raise public voices in protecting the environment.
- **Environmental Compensation:** The act empowers pollution control boards to require polluters to pay environmental compensation for damages caused to the environment. It promotes green and responsible practices.

CENTRAL POLLUTION CONTROL BOARD

It is a statutory organization that was established in 1974 under the Water (Prevention and Control of Pollution) Act, 1974. Later on, it was entrusted with additional functions and power under the Air (Prevention and Control of Pollution) Act, 1981. The CPCB serves as a field formation and provides technical services to the Ministry of Environment and Forests as per the provisions of the Environment (Protection) Act, 1986.

Functions of CPCB

The primary functions of the CPCB include:

- **Setting Standards:** The CPCB is entrusted with the responsibility of formulating national standards to prevent and control pollution in various environmental mediums such as air, water, and soil. These standards serve as reference points for industries and stakeholders to ensure environmental protection.
- **Monitoring and Surveillance:** The CPCB conducts nationwide monitoring and assessment programs to evaluate the quality of ambient air, water bodies, and other environmental parameters. These initiatives aid in identifying pollution sources, assessing pollution levels, and ensuring compliance with environmental standards.
- **Regulatory Compliance:** Ensuring adherence to environmental regulations is a key role of the CPCB. It takes appropriate actions against non-compliant industries and polluters, grants and renews permits, conducts inspections, and implements measures to prevent and control pollution.
- **Capacity Building and Technical Support:** The CPCB extends technical support, guidance, and training to state pollution control boards and other stakeholders, enhancing their capabilities in implementing environmental regulations and pollution control measures.
- **Environmental Impact Assessment (EIA):** The CPCB plays a crucial role in the environmental clearance process for developmental projects. It evaluates Environmental Impact Assessment reports and provides recommendations to the Ministry of Environment, Forest, and Climate Change.

Reports Published by CPCB

Some of the major reports by CPCB are:

- **National Ambient Air Quality Status and Trends:** It provides an analysis of the air quality across different regions of India. In addition, it also shows the levels of various pollutants and their impact on human health and the environment.
- **Water Quality Status:** This report shows the status of water quality in rivers, lakes, and other water bodies, identifying pollution sources and recommending measures for water pollution control and management.
- **Environmental Quality Standards:** The CPCB regularly publishes and update standards for various pollutants in air, water, and soil, providing guidelines for industries, municipalities, and other stakeholders to maintain acceptable environmental quality.
- **Annual Reports:** The CPCB releases annual reports summarizing its activities, achievements, and challenges in the field of environmental protection, including initiatives taken, regulatory actions, and collaborative efforts with stakeholders.

SPCB (State Pollution Control Boards)

Similar to the CPCB, the SPCBs are statutory bodies established under the Water (Prevention and Control of Pollution) Act, 1974. They were later empowered with additional responsibilities under the Air (Prevention and Control of Pollution) Act, of 1981. Moreover, they are entrusted with enforcing the following regulations under the Environment (Protection) Act, 1986:

1. Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016.
2. Environmental Impact Assessment Notification, 2006.
3. Bio-Medical Waste Management Rules, 2016.
4. Plastic Waste Management Rules, 2016.
5. The Noise Pollution (Regulation & Control) Rules, 2000.
6. Construction & Demolition Waste Management Rules, 2016.

7. The Public Liability Insurance Act, 1991.
8. Fly Ash Notification, 1999 and 2008.

SPCBs collaborate with the CPCB at the state level to address pollution issues and enhance environmental well-being.

ENVIRONMENT IMPACT ASSESSMENT

Accordion to Convention on Biological Diversity "Environmental Impact Assessment (EIA) is a process of evaluating the likely environmental impacts of a proposed project or development, taking into account inter-related socio-economic, cultural and human-health impacts, both beneficial and adverse."

Types of Impact Assessment

To approve any project, several types of impacts assessments are undertaken across the world including:

Impact Assessment	Focus	Main Considerations	Purpose
Environmental Impact Assessment (EIA)	Environmental impacts	Air, water, land, ecosystems, natural resources	Evaluate potential environmental effects of projects or activities
Social Impact Assessment (SIA)	Social impacts	Communities, livelihoods, social structures	Assess potential social consequences of projects or policies
Health Impact Assessment (HIA)	Health impacts	Physical, mental, social well-being	Evaluate potential health effects of projects or policies
Economic Impact Assessment (EcIA)	Economic impacts	Employment, income, regional/national economies	Assess potential economic consequences of projects or policies
Climate Change Impact Assessment	Climate change impacts	Greenhouse gas emissions, adaptation strategies	Evaluate potential impacts of projects/policies on climate change
Biodiversity Impact Assessment	Biodiversity impacts	Habitats, species, ecological disruptions	Assess potential impacts on biodiversity and conservation measures
Cultural Heritage Impact Assessment	Cultural heritage impacts	Sites, monuments, traditions, archaeological artifacts	Assess potential impacts on cultural heritage and preservation measures

EIA in India

The concept of Environmental Impact Assessment (EIA) in India emerged during the 1970s in response to concerns regarding environmental degradation and the need for sustainable development. Recognizing the significance of assessing potential environmental impacts, the Indian government introduced EIA processes and regulations to facilitate informed and sustainable decision-making.

Evolution

The evolution of EIA in India can be understood through key milestones:

- **1976:** The establishment of the Environmental Planning and Coordination Organization (EPCO) marked the initiation of environmental planning and the promotion of EIA in the country.
- **1994:** The Ministry of Environment, Forest and Climate Change (MoEFCC) introduced the first comprehensive EIA notification, known as the Environmental Impact Assessment Notification, in 1994. This notification established a regulatory framework for conducting EIAs for various projects.
- **2006:** The EIA notification underwent amendments to strengthen the EIA process. It introduced provisions for public participation, expanded the scope of project categories requiring clearance, and enhanced scrutiny procedures.
- **2022:** The Ministry of Environment, Forest, and Climate Change introduced new changes to the clearance process for development projects.

Key Features of EIA Notification, 2006

The EIA Notification, 2006, encompasses several essential features:

- **Project Categorization:** The notification classifies projects into Category A and Category B. Category A projects necessitate mandatory clearance from the MoEFCC, while Category B projects are assessed and cleared at the state level by the State Environmental Impact Assessment Authority (SEIAA) or State Expert Appraisal Committee (SEAC). Category B projects are further divided into two types:

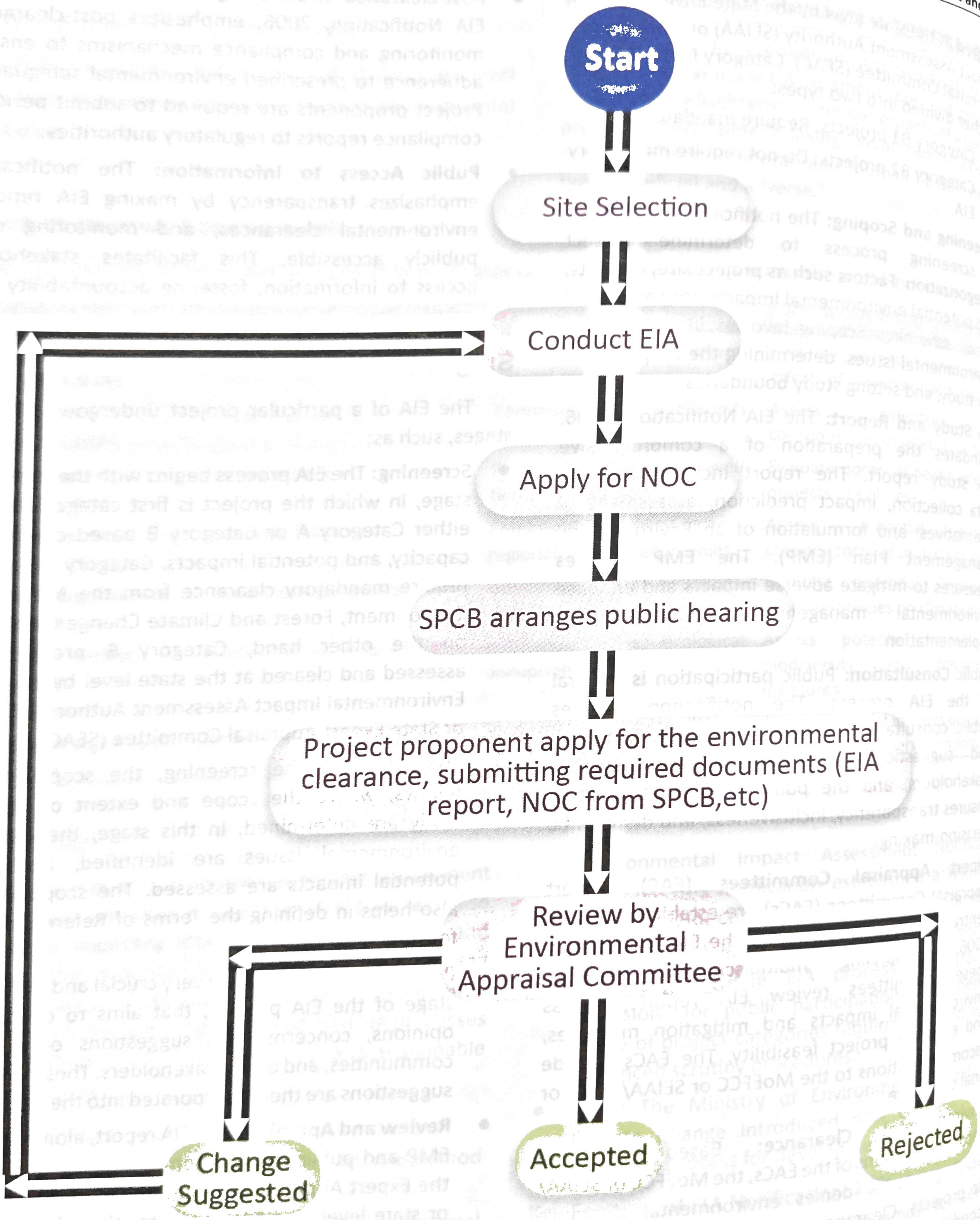
- Category B1 projects: Require mandatory EIA
- Category B2 projects: Do not require mandatory EIA

- **Screening and Scoping:** The notification establishes a screening process to determine project categorization. Factors such as project size, capacity, and potential environmental impacts are considered during screening. Scoping involves identifying key environmental issues, determining the scope of the EIA study, and setting study boundaries.
- **EIA Study and Report:** The EIA Notification, 2006, mandates the preparation of a comprehensive EIA study report. The report includes baseline data collection, impact prediction, assessment of alternatives, and formulation of an Environmental Management Plan (EMP). The EMP outlines measures to mitigate adverse impacts and enhance environmental management during project implementation.
- **Public Consultation:** Public participation is integral to the EIA process. The notification requires public consultation to obtain feedback, concerns, and suggestions from affected communities, stakeholders, and the public. Public consultation ensures transparency, inclusiveness, and democratic decision-making.
- **Expert Appraisal Committees (EAC):** Expert Appraisal Committees (EACs) are established at the central and state levels under the EIA Notification, 2006. Comprising multidisciplinary experts, these committees review EIA reports, assess environmental impacts and mitigation measures, and evaluate project feasibility. The EACs provide recommendations to the MoEFCC or SEIAA/SEAC for final clearance.
- **Environmental Clearance:** Based on the recommendations of the EACs, the MoEFCC or SEIAA/SEAC grants or denies environmental clearance to projects. Clearances may be subject to specific conditions, including compliance with environmental safeguards, monitoring requirements, and reporting obligations.
- **Post-clearance Monitoring and Compliance:** The EIA Notification, 2006, emphasizes post-clearance monitoring and compliance mechanisms to ensure adherence to prescribed environmental safeguards. Project proponents are required to submit periodic compliance reports to regulatory authorities.
- **Public Access to Information:** The notification emphasizes transparency by making EIA reports, environmental clearances, and monitoring data publicly accessible. This facilitates stakeholder access to information, fostering accountability and participation.

Stages of EIA

The EIA of a particular project undergoes different stages, such as:

- **Screening:** The EIA process begins with the screening stage, in which the project is first categorized into either Category A or Category B based on its size, capacity, and potential impacts. Category A projects require mandatory clearance from the Ministry of Environment, Forest and Climate Change (MoEFCC), on the other hand, Category B projects are assessed and cleared at the state level by the State Environmental Impact Assessment Authority (SEIAA) or State Expert Appraisal Committee (SEAC).
- **Scoping:** After the screening, the scoping stage follows, where the scope and extent of the EIA study are determined. In this stage, the different environmental issues are identified, and their potential impacts are assessed. The scoping stage also helps in defining the Terms of Reference (ToR) for the EIA study.
- **Public Consultation**: It is a very crucial and important stage of the EIA process, that aims to collect the opinions, concerns, and suggestions of affected communities, and other stakeholders. These valuable suggestions are then incorporated into the final draft.
- **Review and Appraisal:** The EIA report, along with the EMP and public consultation inputs, is reviewed by the Expert Appraisal Committee (EAC) at the central or state level. The EAC evaluates the adequacy and accuracy of the EIA study, the effectiveness of the proposed mitigation measures, and compliance with environmental norms and guidelines.


Start
Site Selection
Conduct EIA
Apply for NOC
SPCB arranges public hearing
Project proponent apply for the environmental clearance, submitting required documents (EIA report, NOC from SPCB,etc)
Review by Environmental Appraisal Committee
Change Suggested
Accepted
Rejected

EIA Process

Recent Developments

In 2022, the Ministry of Environment, Forest and Climate Change introduced a number of changes to the environmental clearance process for development projects.

Projects which have got exemptions from environmental clearance:

- Highway projects of strategic and defense importance, which are 100 km from the Line of Control.
- Thermal power plants up to 15 MW based on biomass or non-hazardous municipal solid waste using auxiliary fuel such as coal, lignite, or petroleum products up to 15 percent
- Increasing the threshold of ports that exclusively deals in fish handling, and caters to small fishermen
- Toll plazas that need more width for installation of toll collection booths to cater to a large number of vehicles.

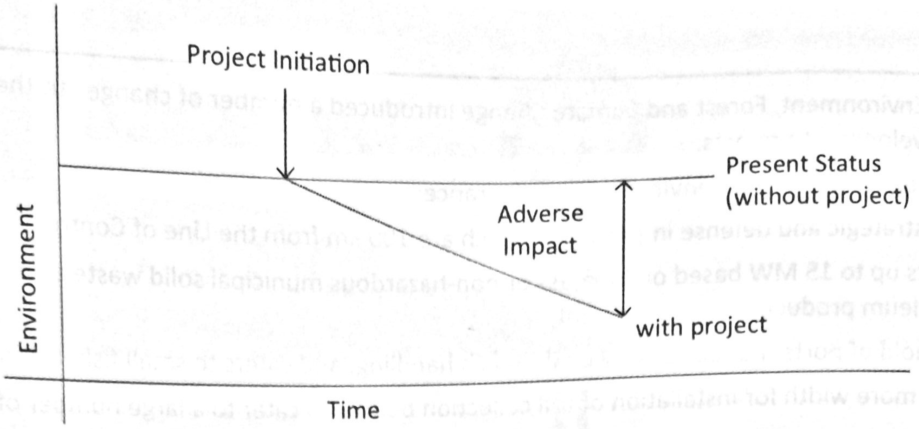
Changes in Validity of Environmental Clearances

Project	**New Tenure of Validity for Environment Clearance**
River Valley Project	**13 years**
Nuclear Power Projects	**15 years**
Mining	**30 years**
Projects other than mining and River Valley	**10 years**

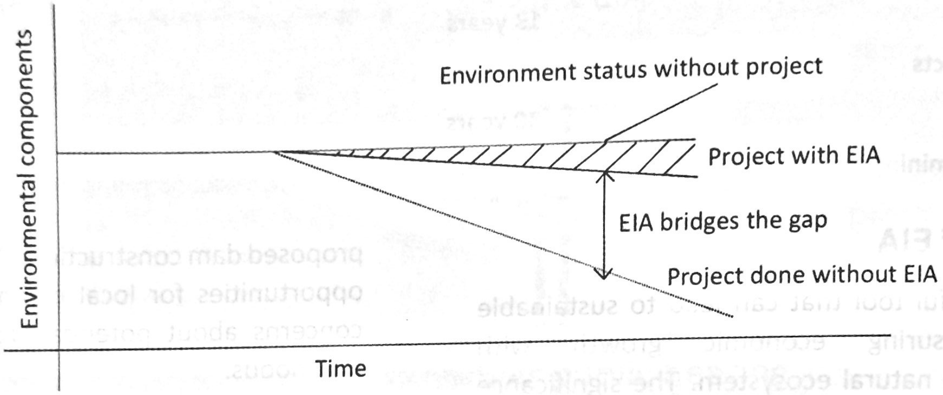
Significance of EIA

EIA is a powerful tool that can lead to sustainable development, ensuring economic growth with preservation of the natural ecosystem. The significance is:

- **Accomplishing long-term growth:** EIA establishes a crucial link between environmental protection and development, enabling both objectives to be addressed simultaneously. For example, a proposed industrial project may undergo an EIA to assess its potential environmental impacts, ensuring that sustainable practices are integrated from the beginning, leading to long-term growth that is in harmony with the environment.
- **Reduced environmental damage:** EIA provides a systematic framework for projects to minimize environmental damage. By identifying potential risks and impacts early on, mitigation measures can be implemented to reduce adverse effects. For instance, a highway construction project may include measures such as wildlife corridors or noise barriers to minimize disruption to ecosystems and nearby communities.
- **Addressing issues of affected individuals:** Through processes like public hearings, EIA ensures the inclusion of individuals who will be impacted by the project. This allows their concerns and suggestions to be considered, fostering a more inclusive decision-making process. For example, in the case of proposed dam construction, the EIA process provides opportunities for local communities to voice their concerns about potential displacement or loss of livelihoods.
- **Preventing natural calamities:** EIA helps prevent natural calamities by assessing and mitigating risks associated with projects. For instance, before the construction of a housing complex in an area prone to landslides, an EIA study may recommend slope stabilization measures to prevent potential disasters.
- **Good relationship among stakeholders:** EIA promotes a positive relationship between the government, developers, environmentalists, and the local community. By involving stakeholders in the decision-making process and addressing their concerns, trust, and collaboration are fostered, leading to more sustainable and socially acceptable projects.
- **Minimizing judicial disputes:** EIA plays a crucial role in minimizing judicial disputes by ensuring that projects undergo a thorough assessment. By addressing potential environmental and social issues proactively, the likelihood of legal challenges is reduced. For example, if a proposed mining project has followed the EIA process diligently, considering impacts on local water bodies and communities, it is less likely to face legal disputes related to environmental degradation.



(a) Anticipated environment impact of development project.



(b) Environment impact rectification after EIA

Environmental Impact System

Issues with EIA in India

Despite being a powerful tool that holds the future course of humankind, it is faced with several issues such as

- **Lack of awareness**: Many local communities and individuals affected by projects lack awareness about the EIA process. This lack of understanding prevents them from actively participating in public consultations and voicing their concerns effectively. It also limits their ability to hold project proponents and regulatory authorities accountable.
- **Unavailability of EIA in local languages:** The EIA documentation is often published in official languages or English, which may not be accessible to local communities who primarily speak regional languages. This language barrier hinders their understanding of the EIA process and their ability to provide meaningful feedback.
- **Ignorance and corruption:** Instances of corruption and lack of transparency within the EIA process have been reported. Some officials involved in EIA committees have been found to engage in malpractices, compromising the objectivity and credibility of the assessment process. This undermines public trust and confidence in the effectiveness of EIA.
- **Loopholes:** The EIA framework may have loopholes and exemptions that can be exploited by large corporations and project proponents. This can lead to the circumvention of the EIA process or inadequate assessment of potential environmental impacts. The screening and scoping processes may lack clarity and consistency, allowing projects to avoid stringent scrutiny.
- **Lack of professionals:** There is a shortage of qualified and experienced Environmental Impact Assessment professionals in India. This shortage can result in errors, omissions, and inadequate assessments during the EIA process. The quality and accuracy of the EIA reports can be compromised, affecting the reliability of the environmental assessment.
- **Iunsufficient public participation:** While the EIA process includes provisions for public consultation, the level of public participation may often be limited or ineffective. The information provided to the public may be inadequate, and consultation meetings may not always be accessible or inclusive. This limits the

meaningful engagement of affected communities and stakeholders in the decision-making process.

- **Limited consideration of cumulative impacts:** The EIA process primarily focuses on individual projects and their immediate impacts. However, it may not adequately address the cumulative impacts of multiple projects in a region. The cumulative impacts of various projects can have significant environmental consequences that need to be carefully assessed and mitigated.
- **Inadequate monitoring and enforcement:** The monitoring and enforcement of compliance with the conditions set in the environmental clearance are sometimes inadequate. This can result in projects not fully adhering to the prescribed mitigation measures and environmental safeguards, leading to environmental degradation and harm to affected communities.

How to strengthen EIA in India?

To achieve the desired outcomes of the EIA process, it is crucial to address these concerns promptly and employ the following strategies:

- **Enhance public involvement and awareness**: Organize campaigns and outreach initiatives to educate local communities about the significance of the EIA process and their participation rights. Translate EIA documents into local languages for better accessibility. Enable meaningful public consultations that facilitate active engagement and incorporation of public input into decision-making.
- **Foster transparency and accountability:** Promote transparent practices by ensuring the disclosure of relevant project information, EIA reports, and monitoring data. Establish mechanisms to hold project proponents and regulatory bodies accountable for their actions. Encourage independent audits and public scrutiny to prevent corruption and irregularities.
- **Strengthen regulatory frameworks:** Review and revise existing EIA notifications to address gaps and exemptions, establishing a more rigorous and standardized assessment process. Provide clear guidelines for the screening and scoping stages. Consider the cumulative impacts of multiple projects within a region to assess their combined environmental effects.
- **Build capacity**: Invest in training programs and capacity-building initiatives for EIA professionals, including experts in environmental science, engineering, and social sciences. Enhance their skills in conducting comprehensive assessments, monitoring, and enforcing compliance. Foster collaboration and knowledge-sharing through workshops and conferences.
- **Independent and expert evaluation:** Establish impartial expert committees with diverse expertise to review EIA reports. Strengthen their role in identifying potential environmental risks and recommending suitable mitigation measures. Encourage the involvement of reputable research institutions and civil society organizations in the review process.
- **Ensure effective monitoring and enforcement:** Strengthen mechanisms for monitoring and enforcing compliance with prescribed mitigation measures and conditions set during environmental clearance. Develop robust systems for regular data collection, monitoring, and reporting. Impose stringent penalties for non-compliance to deter violations and encourage responsible project implementation.
- **Continual review and improvement:** Regularly review the EIA framework to incorporate emerging best practices, scientific advancements, and lessons learned from previous experiences. Engage in ongoing consultations with stakeholders, including communities, industry representatives, and environmental experts, to seek feedback and suggestions for enhancing the EIA process.

In 2022, the Madras High Court invoked the "parens patriae jurisdiction" and declared "Mother Nature" as a "Living Being" having the status of a legal person.

- In 2008, Ecuador became the first country in the world to recognize the rights of nature.
- In 2022, Ecuador became the first country to grant legal rights to individual wild animals
- In 2011, Bolivia granted all nature rights equal to that of humans
- In 2017, New Zealand's Whanganui River became the first in the world to be given legal status.
- In 2017, The Uttarakhand High Court granted the river Ganga and its longest tributary Yamuna the legal right to be protected and not be harmed.

28

INTRODUCTION TO CLIMATE CHANGE

According to the United Nations Framework Convention on Climate Change (UNFCCC), Climate Change refers to the average long-term shift in climatic conditions over the entire Earth. These include warming temperatures and changes in precipitation. Global climate change has occurred very slowly, over thousands or millions of years. However, since the 1800s, human activities have been the main driver of climate change, primarily due to burning fossil fuels like coal, oil and gas. These shifts in the climate are caused due to natural and man-made activities.

GREENHOUSE GASES (GHGS)

Greenhouse gases (GHGs) are gases in Earth's atmosphere that trap heat. These greenhouse gases are similar to the glass panes in a greenhouse. The glass panels of the greenhouse let in the light but keep heat from escaping. Similarly, these gases trap heat in the atmosphere, preventing it from escaping into space.

Greenhouse Effect

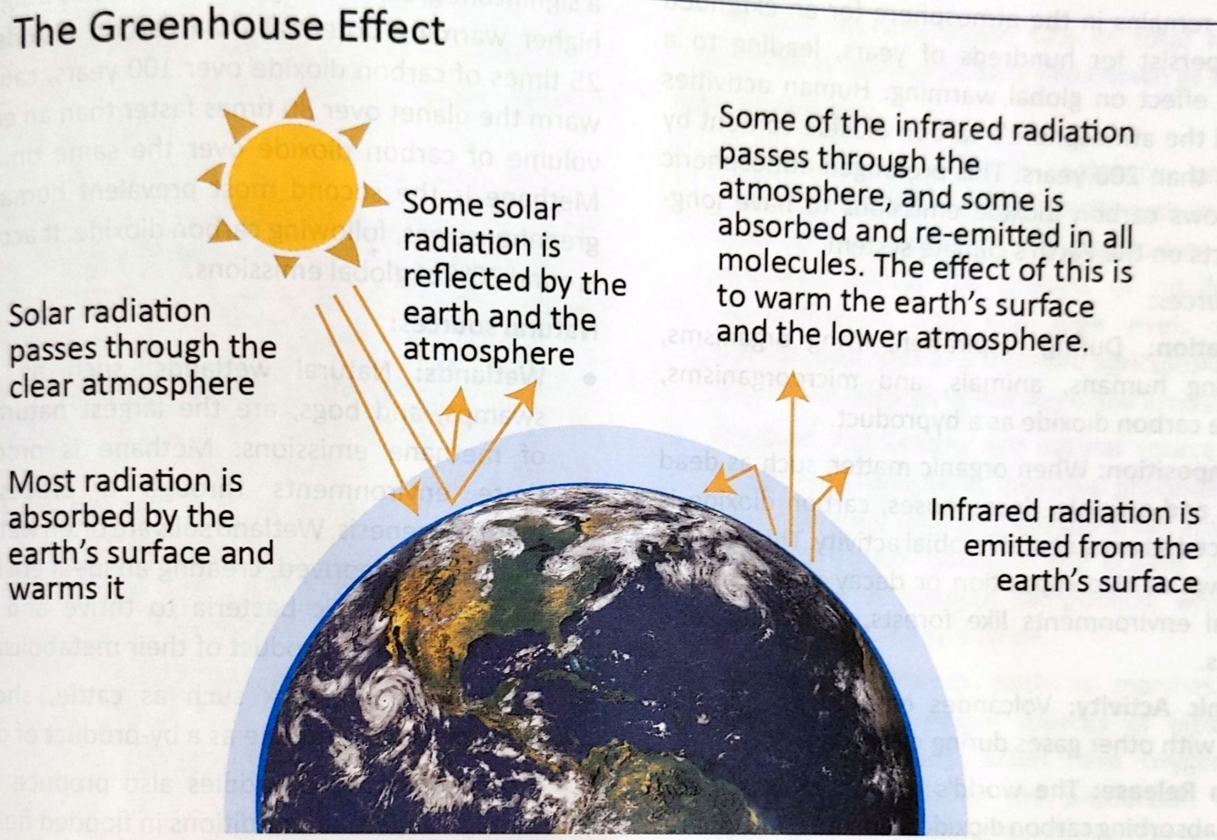
It is a process that occurs when gases in Earth's atmosphere trap the Sun's heat. It occurs naturally in the Earth's atmosphere and plays a vital role in regulating the planet's temperature and making it habitable for life. The Earth has a natural greenhouse effect due to trace amounts of water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the atmosphere. The prime determinants of greenhouse gas effect includes solar radiation, Earth's atmosphere, and the greenhouse gases.

- **Sunlight absorption:** The Sun emits energy in the form of short-range radiation, primarily in the visible and ultraviolet spectrum. This solar radiation travels through space and reaches the Earth. When the solar radiation reaches the Earth's surface, it is absorbed by land, oceans, and vegetation.
- **Greenhouse Gas Transmission:** The greenhouse gases have the ability to absorb and re-emit long-range infrared radiation. These allow sunlight (short-range radiation) to pass through and reach the Earth's surface.
- **Energy Absorption:** After the absorption of solar radiation by the Earth's surface, it warms up. The warmed surface of the Earth emits energy in the form of infrared radiation (heat) as a result of its increased temperature.
- **Greenhouse Gas Absorption:** The greenhouse gases in the atmosphere act like a blanket, trapping or absorbing a portion of the re-emitted long-range infrared radiation. This trapped energy is then radiated in all directions, including back towards the Earth's surface. The re-radiated energy that is directed back to the Earth's surface warms the lower atmosphere and the surface itself.

Significance of Greenhouse Effect

The greenhouse effect helps maintain a balance between incoming solar radiation and outgoing thermal radiation from the Earth. This balance is crucial for the stability of Earth's climate and the preservation of life. The human activities have significantly increased the concentration of greenhouse gases in the atmosphere, primarily through the burning of fossil fuels, deforestation, and industrial processes. This excess of GHGs intensifies the greenhouse effect, leading to global warming and climate change.

Natural greenhouse effect	Enhanced greenhouse effect.
• The natural greenhouse effect is caused by the natural amounts of greenhouse gasses.	• The enhanced greenhouse effect refers to the additional radiative forcing resulting from increased concentrations of greenhouse gasses induced by human activities.
• It is vital to life.	• The main greenhouse gasses whose concentrations are rising are carbon dioxide, methane, nitrous oxide, hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) and ozone in the lower atmosphere.
• In the absence of the natural greenhouse effect the surface of the Earth would be approximately 33 °C cooler.	• Global temperatures have accelerated in the past 30 years and are now the highest since records began.


The Greenhouse Effect
Solar radiation passes through the clear atmosphere
Some solar radiation is reflected by the earth and the atmosphere
Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all molecules. The effect of this is to warm the earth's surface and the lower atmosphere.
Most radiation is absorbed by the earth's surface and warms it
Infrared radiation is emitted from the earth's surface

The Greenhouse Effect

Major Greenhouse Gases

Water vapor

Water vapour is the most abundant greenhouse gas in the atmosphere, accounting for approximately 70% of the total greenhouse effect. Water vapour stays in the atmosphere for a very short period (just a few days).

Characteristics of Water Vapour: Some features of water vapour include

- **Greenhouse Effect:** Like other greenhouse gases, water vapor absorbs and emits infrared radiation in the Earth's atmosphere. It acts as a natural "blanket" by trapping heat and preventing it from escaping into space, thus warming the planet.
- **Latent Heat Release:** When water vapor condenses and forms clouds, it releases latent heat energy. This process further enhances atmospheric instability and lead to the formation of severe weather phenomena such as thunderstorms and cyclones.
- **Positive Feedback:** Water vapor act as a positive feedback mechanism in the climate system. As the Earth's temperature increases due to other greenhouse gas emissions, the amount of water vapor in the atmosphere also tends to increase, amplifying the warming effect.

Sources of Water Vapour

- **Natural Source:** Water vapor is primarily derived from evaporation of liquid water from oceans, lakes, rivers, and other bodies of water. It enters the atmosphere and circulates through the hydrological cycle.

- **Anthropogenic Source:** Human activities, such as burning fossil fuels and land-use changes, indirectly influence water vapor levels by altering the overall climate. While the direct effect of human emissions on water vapor is relatively small compared to natural sources, it increase climate change through its interaction with other greenhouse gases.

Carbon dioxide

Carbon dioxide is a **long-lived greenhouse gas**, meaning it remains in the atmosphere for an extended period. It persist for hundreds of years, leading to a cumulative effect on global warming. Human activities have raised the atmosphere's carbon dioxide content by 50% in less than 200 years. This prolonged atmospheric lifetime allows carbon dioxide emissions to have long-term impacts on the Earth's climate system.

Natural sources:

- **Respiration:**. During respiration, living organisms, including humans, animals, and microorganisms, release carbon dioxide as a byproduct.
- **Decomposition:** When organic matter, such as dead plants and animals, decomposes, carbon dioxide is produced as a result of microbial activity. This process is known as decomposition or decay and occurs in natural environments like forests, grasslands, and oceans.
- **Volcanic Activity:** Volcanoes emit carbon dioxide along with other gases during eruptions.
- **Ocean Release:** The world's oceans act as carbon sinks, absorbing carbon dioxide from the atmosphere. However, they also release carbon dioxide naturally through a process called outgassing.

Anthropogenic sources:

- **Fossil Fuel Combustion:** The burning of fossil fuels such as coal, oil, and natural gas for energy production is the largest source of anthropogenic carbon dioxide emissions. This includes emissions from power plants, industrial processes, transportation (cars, trucks, airplanes, ships), and residential and commercial heating.
- **Deforestation:** When forests are cleared or burned, the carbon stored in trees is released as carbon dioxide. Deforestation for agriculture, logging, and urbanization contributes to carbon emissions.
- **Industrial Processes**: Various industrial processes emit carbon dioxide as a byproduct. For instance, the production of steel, aluminum, chemicals, and other materials involves reactions that release carbon dioxide. Some industrial processes require the use of fossil fuels, contributing to emissions.
- **Waste Decomposition:** Organic waste, such as landfill waste and wastewater treatment, decomposes over time, releasing carbon dioxide and methane.

Methane

Methane is a colorless, odorless, and highly flammable gas. It is a major component of natural gas. Due to its strong heat-absorbing properties, methane is a significant greenhouse gas. Methane has a significantly higher warming potential than carbon dioxide, that is 25 times of carbon dioxide over 100 years, causing it to warm the planet over 80 times faster than an equivalent volume of carbon dioxide over the same time period. Methane is the second most prevalent human-caused greenhouse gas, following carbon dioxide. It accounts for around 20% of global emissions.

Natural sources:

- **Wetlands:** Natural wetlands, such as marshes, swamps, and bogs, are the largest natural source of methane emissions. Methane is produced in these environments through a process called methanogenesis. Wetland soils are often waterlogged and oxygen-deprived, creating an ideal environment for methanogenic bacteria to thrive and produce methane as a by product of their metabolism.
- **Ruminants:** Livestock such as cattle, sheep, and goats produce methane as a by-product of digestion.
- **Rice paddies:** Rice paddies also produce methane through anaerobic conditions in flooded fields.
- **Termites:** Termites are natural sources of methane. They have specialized gut bacteria that help them digest cellulose-rich plant material. During digestion, these gut bacteria produce methane, which is released into the atmosphere through termite exhalation and the breakdown of termite mounds.
- **Oceans:** The world's oceans also release methane into the atmosphere through natural processes. Methane gas bubbles then reach the surface and enter the atmosphere. Certain microorganisms in the ocean, such as archaea, produce methane as part of their metabolic processes.

Anthropogenic sources:

- **Agriculture:** The production of livestock such as cattle, sheep, and goats, as well as rice paddies, release methane through digestive processes. The largest source of anthropogenic methane emissions is agriculture. It is responsible for around a quarter of the total, closely followed by the energy sector. This sector includes emissions from coal, oil, natural gas and biofuels.

- **Fossil fuel production:** The extraction, production, and transportation of fossil fuels such as coal, oil, and natural gas release methane into the atmosphere.
- **Landfills:** Landfills are a significant source of methane, as organic waste in landfills decomposes anaerobically, producing methane.
- **Waste management:** The treatment and disposal of wastewater and solid waste can also release methane into the atmosphere.

Case study: Methane Emission

Methane emission in India

- India ranks as the fourth-largest methane emitter globally, following China, the United States, and Russia.
- With the world's **largest cattle population** and being the **second largest rice producer**, India's agriculture sector releases **five times more** methane compared to the energy sector.
- According to the Global Methane Tracker 2022, agriculture is responsible for 61% of India's total methane emissions, while the energy sector accounts for 16.4% and waste contributes 19.8%.

Methane emission and its effect on the environment

- **Climate Change:** Methane is capable of trapping heat in the atmosphere. Although carbon dioxide remains the primary driver of long-term climate change, methane has higher global warming potential (GWP) compared to carbon dioxide.
- **Smog Formation:** Methane plays a role in the formation of ground-level ozone, commonly known as smog. In the presence of sunlight and other air pollutants, methane reacts to produce ozone.
- **Feedback Loop:** Methane emissions trigger feedback loops that amplify climate change. For instance, as global temperatures rise, permafrost in Arctic regions thaws, releasing previously trapped methane. This additional methane further contributes to warming, potentially leading to a self-perpetuating cycle of increased methane release and elevated temperatures.
- **Ocean Acidification:** Methane dissolved in seawater contribute to ocean acidification. When methane reacts with water, it forms carbonic acid, reducing the pH of the ocean. Ocean acidification poses risks to marine ecosystems.

DO YOU KNOW?

Two cows can release as much greenhouse emissions in one year which is equal to carbon dioxide released by a car in the same period. As per the estimation of Food and Agriculture Organisation (FAO) total emissions from global livestock in terms of carbon dioxide equivalent per year represents 14.5% of all anthropogenic greenhouse gas emissions.

Nitrous oxide

Natural sources create 62% of total emissions of nitrous oxide. Nitrous oxide is also known as laughing gas.

Natural sources:

- **Soils:** Nitrous oxide is naturally produced by microbial activities in soils, particularly in agricultural and natural ecosystems. It is a byproduct of microbial activities during the process of nitrification and denitrification. Soils with high levels of nitrogen, such as wetlands and fertilized agricultural fields, are significant sources of nitrous oxide emissions.
- **Oceans:** The oceans are natural source of nitrous oxide. It is produced by microbial processes in marine environments, including coastal areas and upwelling zones. Nitrogen cycling in the oceans involves the conversion of nitrogen compounds, which lead to the release of nitrous oxide.
- **Wetlands:** Wetlands, such as marshes, swamps, and bogs, are natural sources of nitrous oxide. These environments often have oxygen-depleted conditions, promoting the production of nitrous oxide through microbial denitrification processes.
- **Volcanic Activity:** Volcanoes are natural sources of nitrous oxide, although their contribution to global emissions is relatively small compared to other sources. Volcanic eruptions release nitrous oxide along with other gases into the atmosphere.

Anthropogenic sources:

- **Agriculture:** Agricultural practices are the largest anthropogenic source of nitrous oxide emissions. The use of synthetic and organic fertilizers in farming releases nitrogen into the soil.
- **Industrial Activities:** The production and use of nitrogen-based fertilizers, nylon, and nitric acid are examples of industrial activities that generate nitrous oxide as a by-product. The combustion processes in industries, such as power plants and waste incineration, produce nitrous oxide due to high-temperature reactions involving nitrogen and oxygen.

- **Waste Management:** The decomposition of organic waste in landfills produces nitrous oxide. When organic materials break down in an oxygen-deprived environment, it creates conditions favourable for the production of nitrous oxide through microbial activity.
- **Combustion of Fossil Fuels:** The burning of fossil fuels, including coal, oil, and natural gas, releases nitrous oxide as a by-product of the combustion process.
- **Industrial and Domestic Wastewater Treatment:** The treatment of wastewater in industrial and domestic settings lead to the generation of nitrous oxide. Microbial processes in wastewater treatment plants, particularly during denitrification, produce nitrous oxide as a by-product.

Fluorinated gases

Fluorinated gases, also known as fluorinated greenhouse gases (F-gases), are a group of synthetic gases that contain fluorine atoms. These gases are potent greenhouse gases and have a significant impact on global warming and climate change.These gases are present in very small concentrations in the atmosphere, they trap heat very effectively.

- **Hydrofluorocarbons (HFCs):** HFCs are widely used as substitutes for ozone-depleting substances, such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which have been phased out due to their detrimental effects on the ozone layer. HFCs are primarily used in air conditioning, refrigeration, and foam-blowing applications. While HFCs do not deplete the ozone layer, they have a high global warming potential (GWP) and contribute to climate change.
- **Perfluorocarbons (PFCs):** PFCs are produced through industrial processes and are used in various applications, including electronics manufacturing, semiconductor production, and aluminum production. PFCs have extremely high GWPs and persist in the atmosphere for long periods, contributing significantly to global warming.
- **Sulfur hexafluoride (SF6):** SF6 is used extensively in the electrical industry as an insulating gas for high-voltage equipment, such as circuit breakers, switchgear, and transformers. SF6 has the highest known GWP among all greenhouse gases and remain in the atmosphere for thousands of years.

Natural sources:

- Do not occur in nature

Anthropogenic sources:

- **Refrigeration and Air Conditioning:** Fluorine gases, particularly hydrofluorocarbons (HFCs), are commonly used as refrigerants in refrigeration and air conditioning systems. These gases are used in the cooling and preservation of food, as well as provide comfort in buildings.
- **Foam-Blowing Agents:** Fluorine gases, including HFCs, are used as blowing agents in the production of foams, such as polyurethane foam and polystyrene foam.
- **Fire Suppression Systems:** Certain Fluorine gases, such as hydrochlorofluorocarbons (HCFCs) and perfluorocarbons (PFCs), have been used in fire suppression systems, particularly in specific applications such as data centers, museums, and archives.
- **Electrical Industry:** Sulphur hexafluoride (SF6) is extensively used in the electrical industry as an insulating gas in high-voltage equipment, including circuit breakers, switchgear, and transformers.
- **Manufacturing Processes:** Various industrial processes, such as the production of semiconductors, aluminum, and magnesium, utilize fluorine gases. For instance, perfluorocompounds (PFCs) are used in the semiconductor industry for processes like etching and cleaning of silicon wafers.

Atmospheric Aerosols

Atmospheric aerosols are tiny solid or liquid particles suspended in the Earth's atmosphere. These particles vary in size from a few nanometers to several micrometers. They form both from natural and human-made sources, and have a significant impact on the Earth's climate and air quality.

- **Composition:** Atmospheric aerosols consist of a wide range of substances, including dust, soot, sea salt, sulfate particles, organic compounds, pollen, volcanic ash, and industrial pollutants. The composition of aerosols varies depending on their sources and the region.
- **Size:** Aerosol particles vary in size from a few nanometers (ultrafine particles) to several micrometers (coarse particles). Their size determines their behavior in the atmosphere, including how they scatter and absorb sunlight, interact with gases, and affect cloud formation.

- **Sources:** Aerosols have both natural and anthropogenic sources. Natural sources include volcanic eruptions, dust storms, sea spray, and biogenic emissions from vegetation. Anthropogenic sources include industrial emissions, vehicle exhaust, biomass burning, and power plant emissions.
- **Dispersion and Transport:** Aerosols disperse over long distances by atmospheric circulation patterns. They are transported locally, regionally, or even globally, affecting air quality and climate in remote areas far from their sources.
- **Air Quality:** Aerosols have significant impacts on air quality. Fine particulate matter (PM2.5), which includes many aerosols, penetrate deep into the lungs when inhaled and pose risks to human health. Aerosols also contribute to the formation of smog, reduce visibility, and have adverse effects on respiratory and cardiovascular systems.

Impact of aerosol

Atmospheric aerosols can have both positive and negative impacts on the Earth's climate and Human health. The detailed impact of aerosols are as follows:

- **Reflect and absorb sun light:** Some aerosols reflect sunlight back into space, which can help to cool the Earth's surface. Other aerosols absorb sunlight, leading to warming of the atmosphere. The warming effect of the greenhouse gases is expected to take place everywhere, but the cooling effect of the pollution aerosols will be somewhat regionally dependent, near and downwind of industrial areas.
- **Help in precipitation:** Some aerosols can act as cloud condensation nuclei, which affect the formation and properties of clouds, potentially leading to precipitation.
- **Damage to stratosphere:** Aerosols also act as sites for chemical reactions to take place. The most significant of these reactions are those that lead to the destruction of stratospheric ozone.
- **Health problems:** Aerosols with smaller particle sizes that can penetrate deep into the lungs. These particles have been linked to respiratory and cardiovascular problems.

Aerosol and its impact on Indian monsoon

Researchers from Indian Institute of Tropical Meteorology, Pune, suggest that aerosols weaken the Indian monsoon even more than that of the greenhouse gases

Aerosol and its impact on Indian monsoon

- **Thermal Contrast:** The monsoon is primarily driven by the temperature disparity between the Indian subcontinent and the neighboring ocean. As the land surface heats up, the air above it rises, creating a less dense environment compared to the cooler air over the ocean. The temperature and density contrast prompts moisture-laden winds from the western Indian Ocean to move inland, bringing monsoon rains to the subcontinent.
- **Aerosol Influence:** However, the presence of greenhouse gases, atmospheric aerosols, or increased deforestation can alter this dynamic. Aaerosols have a more significant weakening effect on the monsoon compared to greenhouse gases. Anthropogenic aerosols, such as sulphates, black carbon, nitrates, and dust, accumulate over the Indo-Gangetic plains.
- **Reduction in Solar Radiation:** These aerosols decrease incoming solar radiation over northern India and the northern Indian Ocean, resulting in cooling effects on both land and sea.
- **Weakened Thermal Contrast**: The cooling caused by aerosol accumulation leads to reduced thermal contrast, weakening the monsoon winds and circulation. The cooling effects from aerosols affect both land and sea, contributing to the overall weakening of the monsoon winds.

Aerosol Optical Depth (AOD)

AOD is a measure of the amount of aerosols present in the Earth's atmosphere. It is defined as the extent to which aerosols reduce the transmission of light through the atmosphere at a specific wavelength, and is measured using satellite-based remote sensing techniques or ground-based instruments.

- AOD, expressed as a dimensionless value ranging from 0 to higher values, indicates the concentration of aerosols in the atmosphere.
- The magnitude of AOD is influenced by factors like aerosol particle type, size, humidity, and temperature.
- AOD plays a crucial role in comprehending the effects of aerosols on climate and air quality.
- By measuring AOD, scientists can estimate how much solar radiation is absorbed, scattered, or reflected by aerosols, impacting surface temperature and precipitation patterns.

- AOD data validates and enhances climate models utilized to forecast future climatic conditions.

The Removal of Aerosols

The removal of aerosols from the atmosphere can occur through several natural and human-made processes.

Natural removal processes

- **Deposition:** Aerosols is removed from the atmosphere through deposition, which is the process by which particles are removed from the air and deposited onto surfaces, such as land or bodies of water.
- **Precipitation:** Aerosols is removed from the atmosphere through precipitation, which occurs when the particles become incorporated into cloud droplets and eventually fall to the ground as rain or snow.
- **Photolysis:** Some aerosols is broken down through photolysis, which is the process by which particles are broken down by sunlight.

Human-made removal processes

- **Filtration:** Filtration is a process used in many industrial and residential settings to remove aerosols from the air. Filters can be used to trap particles, preventing them from being released into the atmosphere.
- **Scrubbers:** Scrubbers are devices that use a liquid or gas to capture and remove aerosols from industrial emissions.
- **Electrostatic precipitation:** Electrostatic precipitation is a process that uses electrically charged plates to remove particles from the air.

The Multi-Angle Imager for Aerosols Mission (MAIA)

NASA and the Italian Space Agency ASI has collaborated to the development and launch of MAIA, also known as the Multi-Angle Imager for Aerosols missions.

Objective: The MAIA mission aims to examine the health consequences resulting from minute airborne particles that contaminate highly populated cities worldwide. The primary objective of this satellite mission is to comprehend the implications of diverse forms of particle pollution on human well-being.

Details:

- Scheduled for deployment by the end of 2024.
- The MAIA observatory will comprise of PLATiNO-2, a satellite designed by ASI, and a scientific instrument constructed at NASA's Jet Propulsion Laboratory situated in southern California.
- The mission looks forward to gathering and scrutinize data from the observatory, ground-based sensors, and atmospheric models for comprehensive analysis.

Significance of the Mission:

- Inhaling airborne pollution particles has been connected to numerous health complications, although the precise toxicity of various particle combinations remains relatively unclear.
- MAIA's mission will contribute to our understanding of how airborne particle pollution endangers our health, offering potential insights that can guide the decision-making processes of public health officials and policymakers.

Black Carbon (Soot-Form of Aerosol Particles)

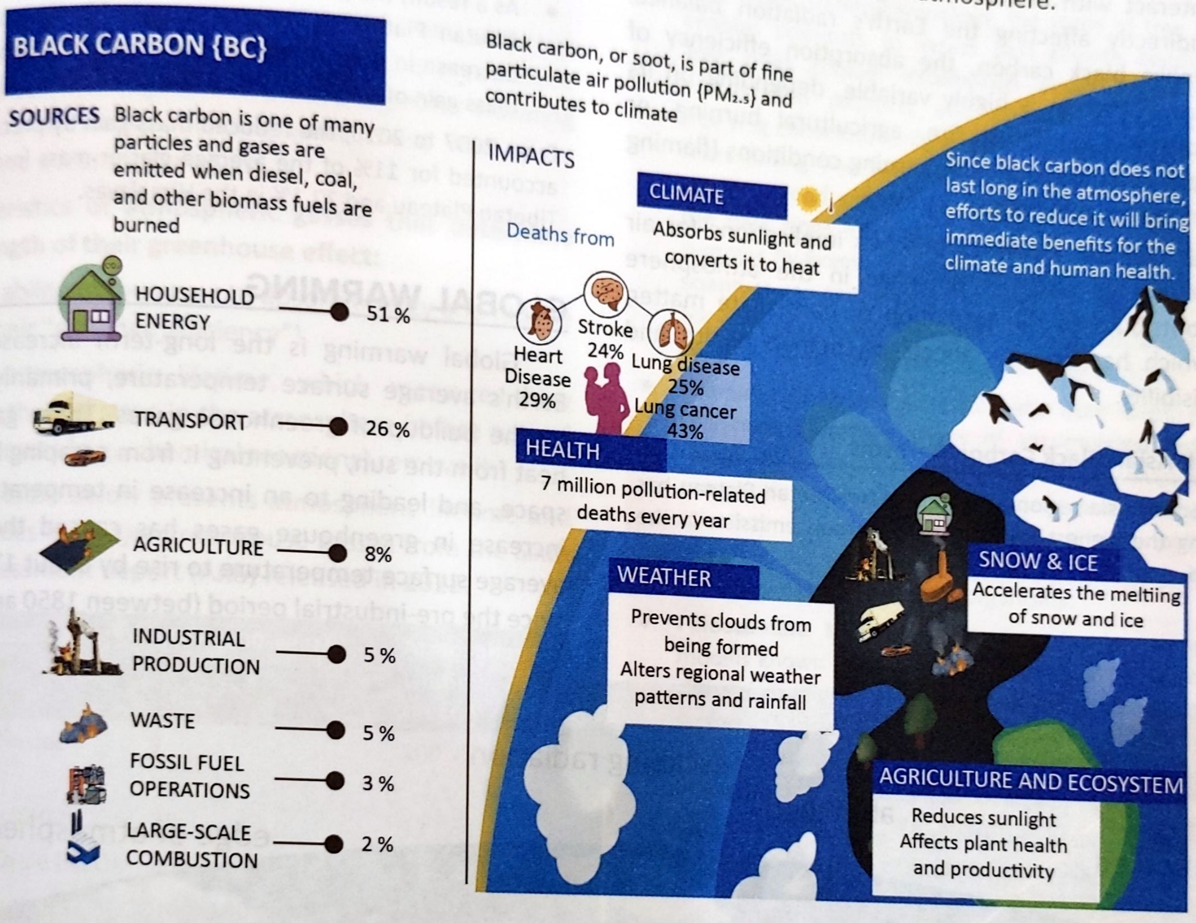
Black Carbon is a form of aerosol particle emitted from incomplete combustion of fossil fuel, biofuels and biomass. It is emitted in both anthropogenic and naturally occurring soot. It consists of pure carbon. Black carbon (BC) is a component of fine particulate matter (PM2.5). While natural sources of black carbon exist, human-made sources are typically responsible for the majority of black carbon emissions. It is a short-lived climate pollutant with a lifetime of only days to weeks after release in the atmosphere. It is very effective at absorbing light and heating its surroundings. Per unit of mass, black carbon has a warming impact on climate that is 460-1,500 times stronger than carbon dioxide. Household cooking and heating account for 51% of global black carbon emissions.

Natural sources:

- **Wildfires:** Natural wildfires release significant amounts of black carbon into the atmosphere. Wildfires are typically caused by lightning strikes, but can also be started by human activity or other natural causes.
- **Volcanic eruptions:** Volcanic eruptions release large amounts of black carbon, along with other gases and particles, into the atmosphere. The amount of black carbon emitted by a volcano vary depending on the type and size of the eruption.
- **Dust storms:** Dust storms, which is caused by natural factors such as wind and drought, that also contribute to black carbon emissions. Dust storms transport large amounts of dust and other particles over long distances, leading to increased concentrations of black carbon in the atmosphere.
- **Oceanic sources:** Oceanic sources of black carbon include sea spray, which can contain black carbon particles generated from the combustion of marine fuels in shipping traffic.

Anthropogenic sources:

- **Transportation:** Black carbon is emitted from the exhaust of vehicles, especially diesel-powered vehicles, and aircraft.
- **Industrial processes:** The combustion of fossil fuels, such as coal and oil, in industrial processes, such as power generation and manufacturing, emit black carbon.
- **Residential and commercial sources:** The use of solid fuels, such as wood, coal, and biomass, for cooking and heating in homes and commercial buildings, are a significant source of black carbon emissions.
- **Waste burning:** Open burning of waste, including municipal solid waste and agricultural waste, release black carbon into the atmosphere.


BLACK CARBON {BC}
Black carbon, or soot, is part of fine particulate air pollution {PM2.5} and contributes to climate
SOURCES
Black carbon is one of many particles and gases are emitted when diesel, coal, and other biomass fuels are burned
HOUSEHOLD ENERGY 51 %
TRANSPORT 26 %
AGRICULTURE 8%
INDUSTRIAL PRODUCTION 5 %
WASTE 5 %
FOSSIL FUEL OPERATIONS 3 %
LARGE-SCALE COMBUSTION 2 %
IMPACTS
CLIMATE
Absorbs sunlight and converts it to heat
Since black carbon does not last long in the atmosphere, efforts to reduce it will bring immediate benefits for the climate and human health.
Deaths from
Heart Disease 29%
Stroke 24%
Lung disease 25%
Lung cancer 43%
HEALTH
7 million pollution-related deaths every year
WEATHER
Prevents clouds from being formed
Alters regional weather patterns and rainfall
SNOW & ICE
Accelerates the meltiing of snow and ice
AGRICULTURE AND ECOSYSTEM
Reduces sunlight
Affects plant health and productivity

Black Carbon

Brown Carbon

Brown carbon refers to a type of organic carbonaceous material that absorbs light in the visible to ultraviolet (UV) spectrum. It is distinct from black carbon, as it absorbs light in the visible and near-infrared spectrum. Brown carbon gets its name from the brownish color it imparts when concentrated. It coexists with black carbon when released into the atmosphere. Both Black and Brown carbon aid Global Warming and pollution.

- **Composition:** Brown carbon is composed of organic compounds, primarily formed through the incomplete combustion of biomass, such as wood, crop residues, and biofuels. It is also produced through other sources like fossil fuel combustion, cooking emissions, and biomass burning in wildfires.
- **Optical Properties:** Brown carbon exhibits strong light absorption in the shorter wavelengths, particularly in the Ultra Violet and blue regions of the electromagnetic spectrum. This absorption lead to localized heating of the atmosphere and influence the radiative balance.
- **Sources:** Brown carbon is emitted by various sources, including open biomass burning, residential cooking and heating, industrial processes, and transportation. It is emitted as primary particles or formed through secondary processes involving chemical reactions in the atmosphere.
- **Atmospheric Presence:** Brown carbon is found in both the troposphere (lower atmosphere) and the stratosphere (upper atmosphere). It is transported

over long distances by atmospheric circulation patterns and contribute to regional and global climate effects.

- **Climate Effects:** Its light-absorbing properties influence radiation, affecting atmospheric heating rates and temperature profiles. Brown carbon also interact with clouds, altering their properties and indirectly affecting the Earth's radiation balance. Unlike black carbon, the absorption efficiency of brown carbon is highly variable, depending on its sources (i.e., forest fire, agricultural burning, or residential cooking) and burning conditions (flaming versus smouldering).
- **Air Quality:** Brown carbon has implications for air quality as well. Its presence in the atmosphere contribute to the formation of particulate matter, which has adverse effects on human health and visibility.

South Asian Black Carbon Aerosols

The South Asia region adjacent to the Tibetan Plateau has among the highest levels of black carbon emission in the world.

- Black carbon aerosols present in South Asia have the capability to elevate temperatures in the middle and upper atmosphere, resulting in an amplified North-South temperature gradient. Consequently, this intensifies convective activity in the region, leading to the convergence of water vapor in South Asia.
- Black carbon also increases the number of cloud condensation nuclei in the atmosphere
- As a result, the precipitation in the central and southern Tibetan Plateau is reduced during the monsoon. The decrease in precipitation further leads to a decrease of mass gain of glaciers.

From 2007 to 2016, the reduced mass gain by precipitation accounted for 11% of the average glacier mass loss on the Tibetan Plateau and 22.1% in the Himalayas.

GLOBAL WARMING

Global warming is the long-term increase in the Earth's average surface temperature, primarily caused by the buildup of greenhouse gases. These gases trap heat from the sun, preventing it from escaping back into space, and leading to an increase in temperature. This increase in greenhouse gases has caused the Earth's average surface temperature to rise by about 1°C (1.8°F) since the pre-industrial period (between 1850 and 1900).

Global Warming Potential

Global Warming Potential (GWP) is a measure used to compare the potential of different greenhouse gases to contribute to global warming over a specific time period, usually 100 years, relative to carbon dioxide. It is a standardized metric that helps assess the relative impacts of different greenhouse gases based on their warming potentials.

carbon dioxide is assigned a GWP of 1 and serves as the baseline for calculating the GWP of other greenhouse gases. Gases with higher GWPs have a greater warming potential than carbon dioxide, while those with lower GWPs have a lesser potential.

Characteristics of atmospheric gasses that determine the strength of their greenhouse effect:

- The ability of the gases to absorb energy and radiate it (their "radiative efficiency").
- The atmospheric lifetime, which measures how long the gas stays in the atmosphere before natural processes (e.g., chemical reactions) remove it.

The table below presents atmospheric lifetime and GWP values for major greenhouse gasses from the Sixth IPCC Assessment Report (AR6) released in 2022.

Greenhouse Gas	GWP (100-year)	Atmospheric Lifetime (years)
Carbon Dioxide (CO2)	1	100
Methane (CH4)	28	12
Nitrous Oxide (N2O)	265	120
Hydrofluorocarbon (HFCs)	from 140 to 11,700	1-270
Perfluorocarbon (PFCs)	from 6,500 to 9,200	800-50,000
Sulphur hexafluoride (SF6)	23,500	3,200

CLIMATE CHANGE

How scientists determine past global warming and climate change events

Scientists analyze proxy records, which are indirect indicators of past climate conditions. These proxies include ice cores, tree rings, sediment cores, coral reefs, and historical records. By studying these proxies, scientists can infer temperature variations, atmospheric composition, and other climate parameters over different periods of history.

- **Ice Core Analysis:** Ice cores extracted from glaciers and ice sheets provide valuable information about past climates. Scientists examine air bubbles trapped within the ice, analyzing the composition of gases such as carbon dioxide and methane. The analysis helps reconstruct past temperature changes and atmospheric conditions over thousands of years.
- **Tree Rings:** Dendrochronology, the study of tree rings, enables scientists to assess past climate conditions. Tree rings contain information about temperature, precipitation patterns, and growing conditions.Each tree ring consists of a light ring followed by a dark ring, representing one year of the tree's life. The light ring signifies wood growth during the early summer, while the dark rings indicate wood growth during the late summer. By examining the color and width of tree rings, scientists can gain insights into past climate conditions. For instance, wider tree rings usually indicate wetter years, while narrower rings suggest drier periods.
- **Sediment Analysis:** Sediment cores from lakes, rivers, and oceans contain layers of accumulated material that provide insights into past climate. By analyzing the composition and properties of these sediment layers, scientists can decipher historical climate patterns, including temperature variations, precipitation levels, and the presence of specific organisms.
- **Paleoclimate Modeling:** Scientists develop computer models known as paleoclimate models to simulate past climate conditions. These models incorporate various factors, including greenhouse gas concentrations, solar radiation, and volcanic activity, to simulate and understand historical climate changes.
- **Radiocarbon Dating:** Radiocarbon dating is used to determine the age of organic materials, such as plant remains or fossils, up to around 50,000 years old. By dating these materials, scientists can establish timelines and correlations with climate changes observed in other proxy records.
- **Pollen Analysis:** Pollen preserved in sediment or peat bogs provides insights into past vegetation and climate conditions. By examining pollen types and abundance, scientists can reconstruct past climate patterns and changes in ecosystems.

Factors Affecting Climate Change

Natural Factors

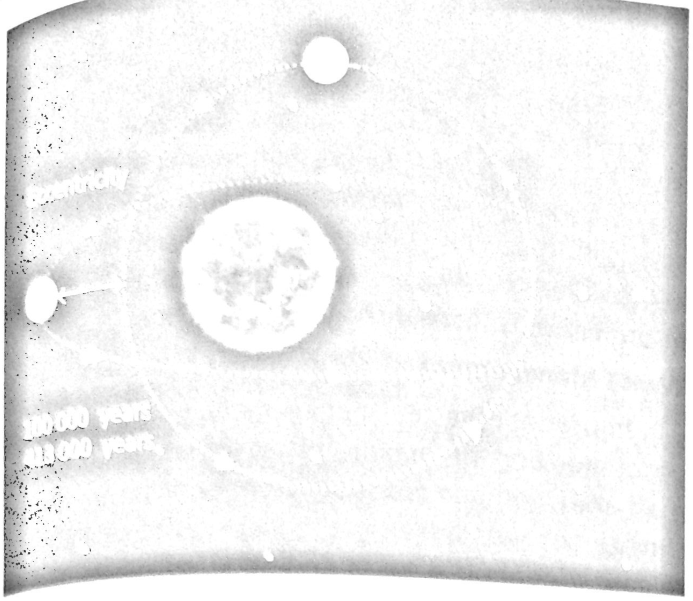
- **Variation in solar radiation:** Around 30 percent of the solar energy that strikes Earth is reflected back into space. Clouds, atmospheric aerosols, snow, ice, sand, ocean surface and even rooftops play a role in deflecting the incoming rays. The remaining 70 percent of solar energy is absorbed by land, ocean, and atmosphere. The energy output of the Sun is not constant: it varies over time and this has an impact on the climate.

Earth's climate depends on the delicate balance between incoming solar radiation, outgoing thermal radiation and the composition of Earth's atmosphere. Even small changes in these parameters can affect climate.

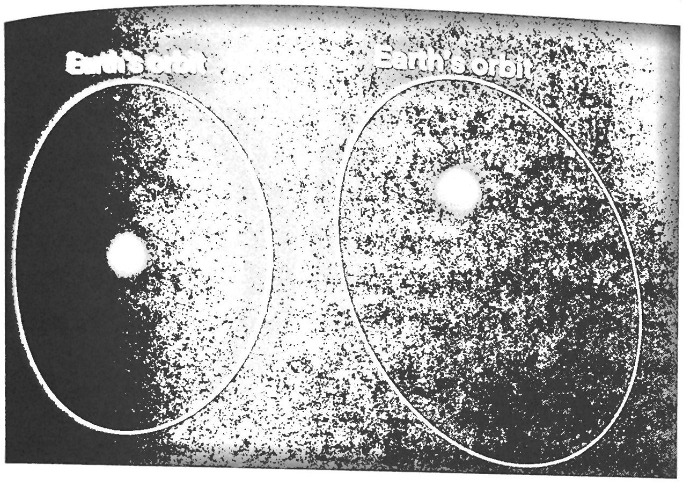
Do You Know?

Scientists use a metric called **Total Solar Irradiance (TSI)** to measure the changes in energy the Earth receives from the Sun. TSI incorporates the 11-year solar cycle and solar flares/storms from the Sun's surface. Studies show that solar variability has played a role in past climate changes. For example, a decrease in solar activity coupled with increased volcanic activity helped trigger the Little Ice Age.

- **Changes of the Earth over long period of time:** The three changes in the Earth's orbit around the Sun are: eccentricity, axial tilt, and precession. They are collectively called **'Milankovitch cycles'.** According to Milankovitch's theory, these three cycles combine to affect the amount of solar heat that reaches the Earth's surface and subsequently influences climatic patterns, including periods of glaciation (ice ages).
- **Changes in the Earth's orbit:** The Earth's orbit around the Sun is an ellipse (an oval shape), but it isn't always the same shape of ellipse. Sometimes, it is almost circular. The earth's orbit changes shape over a cycle of 90,000 to 100,000 years. This will change the eccentricity (Effective distance) between the Earth and the Sun. This change leads to fluctuations in the amount of heat received at different parts of the planet.from the sun. This can cause variations in the Earth's climate and result in long-term changes, such as ice ages.
- **Changes in the Earth's axial tilt:** The Earth's axial tilt, or the angle at which it rotates relative to the sun, can also affect the amount of solar radiation received at different parts of the planet. The earth's axis also changes, leading to changes in its tilt and resulting in gradual shifts in climate over a cycle of 41,000 years. This results in variations in the Earth's climate.
- **The Earth's precession:** The Earth wobbles on its axis, much like a spinning top that is slowing down. This is called 'precession' and is caused by the gravitational pull of the Moon and the Sun upon the Earth. This means that the North Pole changes where it points to in the sky. Currently the Earth's axis points at Polaris, the North Star, but over thousands of years the axis moves around in a circle and points at different parts of the sky. It impacts on the seasonal contrasts between hemispheres and the timing of the seasons consequently leading to climate change.



Eccentricity



Earth's Orbit

- **Volcanic Eruption:** Volcanoes affect the climate through the gasses and particles (tephra/ash) thrown into the atmosphere during eruptions. These Volcanic eruptions can contribute to climate change in several ways.
- the ash and sulfur dioxide released into the atmosphere during an eruption reflect sunlight and cool the Earth's surface. Volcanic dust has been linked to historical climate events such as the Little Ice Age and is believed to have played a role in initiating ice ages in the geological past
- Large volcanic eruptions release huge amounts of carbon dioxide and other greenhouse gasses into the atmosphere, leading to a warming of the planet over time.
- The ash and sulfur dioxide also form aerosols, which linger in the atmosphere for several years and ave a cooling effect on the planet during this time.

DO YOU KNOW?

Climate change is generally associated with global warming. However some small areas like the tropical Pacific show that the release of aerosols into the atmosphere has actually cooled (or at least warmed much slower than the rest of the world).

- **Plate Tectonics:** Plate tectonics, the movement of the Earth's crustal plates, contribute to climate change in several ways.
- Volcanic activity, which is associated with plate tectonics, releases greenhouse gasses such as carbon dioxide and methane into the atmosphere, contributing to global warming.
- Plate tectonics also cause changes in ocean currents and the distribution of land and ocean on the planet, which impact the Earth's climate. For example, the formation of new oceanic crust at mid-ocean ridges and the subduction of old oceanic crust beneath continental margins alter ocean currents, affecting the transport of heat and other elements. This leads to changes in the Earth's climate.
- The movement of tectonic plates causes the creation or destruction of land masses, affecting the distribution of land and ocean and influencing global weather patterns. For example, Large mountain chains influence the circulation of air around the globe, and consequently influence the climate. Like, warm air is deflected to cooler regions by mountains.
- **Ocean Currents:** Ocean currents play a significant role in determining the Earth's climate by transporting heat and moisture around the planet. Changes in ocean currents impact regional and global climate patterns. One of the most significant ways that ocean currents cause climate change is through their effect on the ocean-atmosphere heat exchange. For example, changes in ocean currents alter the transport of warm water from the equator to the poles. This will lead to changes in the temperature distribution on the planet. Ultimately affecting the global climate. Changes in ocean currents influence the amount of heat that is stored in the ocean, which have long-lasting impacts on the Earth's climate.
- **El-nino-Southern Oscillation:** The El Nino-Southern Oscillation (ENSO) is a naturally occurring climate pattern that is driven by fluctuations in ocean temperatures in the Pacific Ocean. The ENSO have a significant impact on the Earth's climate, particularly in the tropical Pacific region and in adjacent

continents. During an El Nino event, warm water from the western Pacific shifts eastward, leading to a warming of the surface waters in the central and eastern Pacific. This shift in ocean temperatures alter weather patterns around the world, including causing drought in some regions and heavy rainfall in others. On the other hand, during a La Niña event, the opposite occurs, with cooler water from the east moving westward and leading to cooling of the surface waters in the central and eastern Pacific.

Anthropogenic Factors

Anthropogenic factors refer to human activities that contribute to climate change by altering the Earth's energy balance and increasing the concentrations of greenhouse gases in the atmosphere. Since the beginning of the Industrial Revolution, fossil fuels were burnt in large quantities and vast areas of land were changed from forests to farmland.

The burning of fossil fuels (coal, oil, and natural gas)

It releases large amounts of carbon dioxide and other Greenhouse Gasses into the atmosphere. These Greenhouse Gasses (GHGs) trap heat and cause global temperatures to rise. For instance, India is one of the world's largest consumers of fossil fuels. A recent study emphasizes the need for a yearly 3% reduction in global fossil fuel production until 2050 in order to limit global warming to below the 1.5°C target set by the Paris Agreement.

Deforestation

Trees absorb carbon dioxide from the atmosphere, so cutting down forests and not replanting them can increase the amount of carbon dioxide in the atmosphere. For instance, The clearing of forests in Madhya Pradesh releases large amounts of carbon dioxide into the atmosphere, contributing to climate change. The forests in the region are estimated to store around 14 million tonnes of carbon, and their destruction is releasing this carbon back into the atmosphere.

Agricultural practices

Agricultural activities, such as the use of fertilizers and the raising of livestock, also release greenhouse gasses. For instance, rice is a major crop in India, and the residue left over after harvest (known as rice straw) is often burned as a way to clear fields for the next crop. Rice straw burning releases large amounts of greenhouse gases, including carbon dioxide and methane, into the atmosphere. In addition, it contributes to air pollution and poses health risks to those who are exposed to the smoke.

Land use changes

Urbanization and other land use changes can also contribute to climate change by altering the balance between carbon dioxide uptake and release. Carbon dioxide is the main cause of human-induced climate change. The conversion of forest land into agricultural land not only reduces the ability of the land to sequester carbon but also releases large amounts of carbon dioxide into the atmosphere through deforestation.

Waste Management

Improper waste management, particularly the decomposition of organic waste in landfills, produces methane. Methane emissions from landfills contribute to climate change. Similarly, the incineration of waste can release greenhouse gases and other pollutants into the atmosphere.

Industrial and Residential Energy Use

The consumption of energy in industrial processes, residential buildings, and commercial establishments contributes to greenhouse gas emissions. This includes the burning of fossil fuels for electricity generation, heating, cooling, and other energy needs.

Outdoor air pollution in India affects over 70% of the population, resulting in one out of every eight deaths and reducing the average life expectancy of Indians by nearly two years.

Transportation

The combustion of fossil fuels in vehicles, including cars, trucks, ships, aeroplanes, and trains, is a major source of greenhouse gas emissions. The reliance on fossil fuels in the transportation sector contributes significantly to climate change.

Out of all emissions, the transport sector contributes to a quarter, with road transport alone responsible for three-quarters of transport emissions and 15% of total global carbon dioxide emissions. Among the various contributors, passenger vehicles constitute the largest portion, emitting approximately 45% of carbon dioxide. If the current conditions persist, it is projected that annual greenhouse gas (GHG) emissions in 2050 will be 90% higher compared to those of 2020.

Short-lived climate pollutant

Short-Lived Climate Pollutants (SLCPs) exhibit a relatively brief lifespan in the atmosphere, ranging from a few days to a few decades. Despite their transient nature, the warming potential of SLCPs can surpass that of CO2 by multiple folds. These pollutants contribute up to 45% of the existing global warming, second only to CO2. Some examples of SLCPs encompass black carbon, methane, tropospheric ozone, and hydrofluorocarbons.

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IMPACT OF CLIMATE CHANGE

The impacts of climate change are far-reaching and encompass various aspects of our lives, ecosystems, and the planet as a whole. From rising temperatures and sea levels to more frequent and severe extreme weather events, climate change poses significant threats to the environment, human societies, and the economy.

Extreme Climate Change events that used to be rare are now becoming more frequent. However, the impacts of climate change are not uniform. Some statistics are highlighted to prove that climate change is an ongoing phenomenon. For instance, the planet has already warmed 1.1 degrees Celsius since the preindustrial era (began 250 years ago). Scientists warn it could reach a worst-case scenario of 4 degrees Celsius by 2100, if we fail to tackle the causes of climate change—namely, the burning of fossil fuels (coal, oil, and gas).

IPCC Sixth Assessment Report

The third part of the Sixth Assessment Report (AR6) was released by IPCC, titled 'Climate Change 2022: Mitigation of Climate Change', the Working Group III contribution to the Sixth Assessment Report

Key Findings of the Report

Greenhouse Gas Emissions:

- In 2019, global net anthropogenic Greenhouse Gas (GHG) emissions were at 59 Gigatons of carbon dioxide equivalent (GtCO2e), 54% higher than in 1990
- Burning of fossil fuels and the industrial sector, as well as methane emissions were main drivers of GHG emissions.
- Average annual GHG emissions were higher than any previous decade during 2010- 19 decade, though rate of growth was lower.
- At least 18 countries have reduced GHG emissions for longer than 10 years

Emission by the Least Developed Countries

- Carbon inequality remains pervasive as ever with Least Developed Countries (LDCs) emitting only 3.3% of global emissions in 2019.
- LDCs contributed less than 0.4% of total historical carbon dioxide emissions from fossil fuels and industry in the period 1850-2019

Regional Variations in contributions to global GHG emissions

- Globally, 41% of the world's population lived in countries emitting less than 3 tCO2e per capita in 2019.
- 10% of households with the highest per capita emissions contribute a disproportionately large share of global household GHG emissions.

Finance Shortfall

- Financial flows fall short to achieve the ambitious mitigation goals to limit warming to below 1.5°C or 2°C
- Agriculture, forestry, and other land uses (AFOLU) sector saw the least financial support

Failure to meet targets of Paris Agreement:

- IPCC finds that it is likely that global warming will exceed 1.5 degrees Celsius (°C) in this century
- The carbon dioxide emissions from existing and planned fossil fuel infrastructure contribute to this projected failure.
- IPCC outlines what the world needs to limit temperatures to 1.5°C, with limited or no 'overshoot' also known as C1 Pathway by reducing 43% GHG emission by 2030.

HEAT WAVES

Heat waves are prolonged periods of excessively hot weather, typically lasting for several days or even weeks. During a heat wave, temperatures rise significantly above the average for a particular region, and the hot conditions persist for an extended period.

Impact of climate change on heatwaves:

Climate change is a significant factor in the increasing frequency, intensity, and duration of heat waves.

- **Rising temperatures:** Climate change leads to increase in global temperatures and warms planet warms. This results in frequent and intense heat waves. Higher ground temperatures make it easier for extreme heat events to occur and persist for longer periods.
- **Amplified heat extremes:** Climate change amplify existing natural climate variability, leading to more

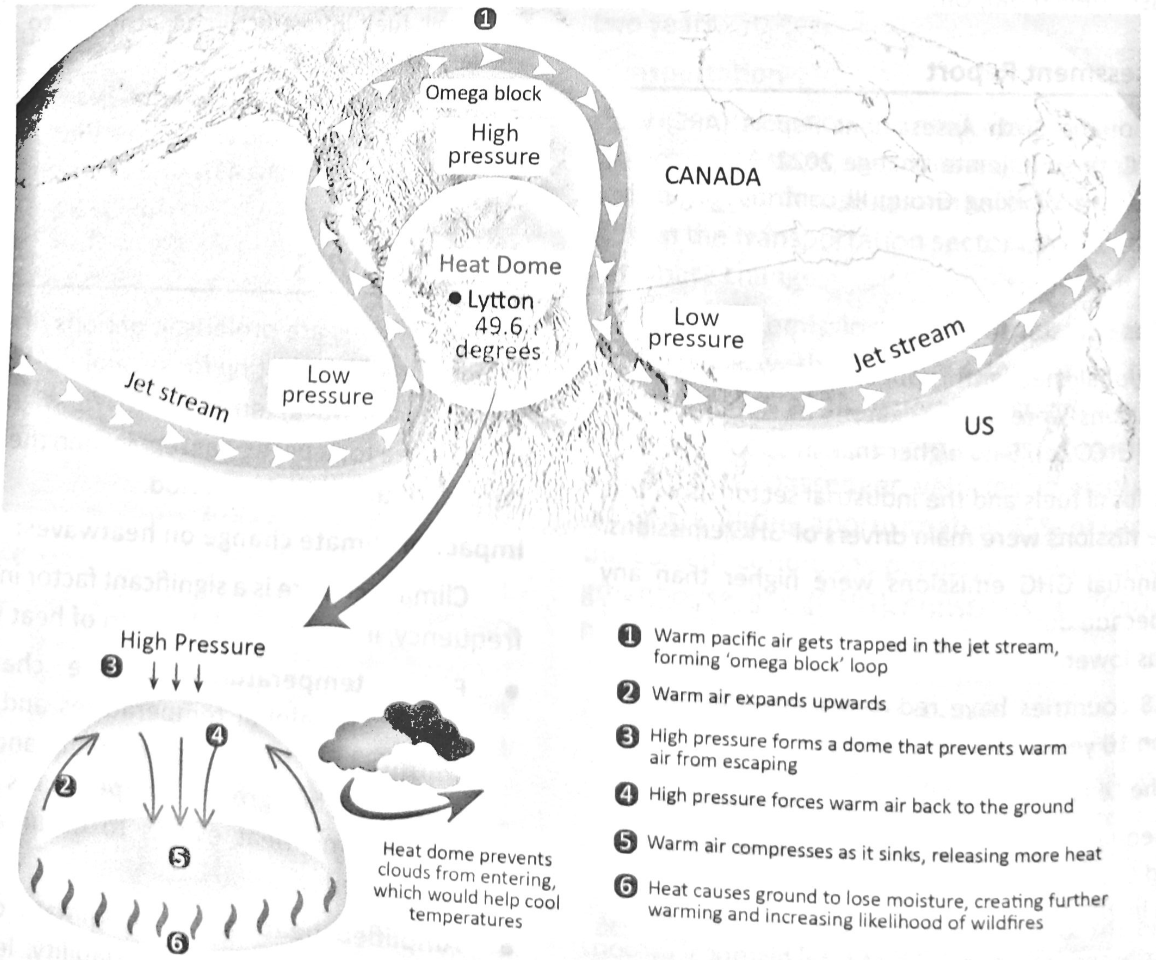
extreme heat events. The warming climate alters atmospheric circulation patterns and create stagnant high-pressure systems that trap heat over a region, intensifying a heat wave's impact.

- **Heat dome formation:** Climate change contribute to the formation of heat domes, which are areas of high pressure that trap hot air and lead to prolonged heat waves. The rise in formation of these heat domes is attributed to changing atmospheric circulation patterns influenced by climate change.
- **Drought conditions:** Climate change induced droughts lead to drier soils and reduced water availability, which amplify the heating effect. Thus, making heat waves more severe and increasing the risk of wildfires.
- **Feedback loops:** Heat waves trigger feedback loops that further amplify its own effects. For instance, during a heat wave, increased evaporation rates from land and water bodies lead to higher humidity levels, increasing the discomfort and health risks associated with high temperatures.
- **Sea level rise and coastal heat waves**: Climate change-induced sea level rise contribute to coastal heat waves. As coastal areas experience higher temperatures due to the warm ocean currents, rising sea levels limit the ability of these areas to dissipate heat, intensifying the impact of heat waves on coastal communities.

Heat Dome

A heat dome is a massive formation of warm air trapped under an area of high pressure for an extended period. The phenomenon is similar to that a lid on a pot. The high-pressure acts as a barrier, confining warm air within a specific region. The longer the warm air remains trapped, the more it absorbs heat from the sun, resulting in increasingly higher temperatures.

- Heat domes typically persist for a few days but can endure for weeks, contributing to prolonged and potentially dangerous heatwaves.
- The compression of air as it sinks under high pressure causes it to become even warmer once it reaches the ground.
- As the air descends, it also becomes drier, exacerbating the heat and aridity of the affected area.
- Heat domes can lead to severe heat-related health issues, ecosystem stress, and increased energy demand for cooling.



❶ Warm pacific air gets trapped in the jet stream, forming 'omega block' loop

❷ Warm air expands upwards

❸ High pressure forms a dome that prevents warm air from escaping

❹ High pressure forces warm air back to the ground

❺ Warm air compresses as it sinks, releasing more heat

❻ Heat causes ground to lose moisture, creating further warming and increasing likelihood of wildfires

Heat waves in India

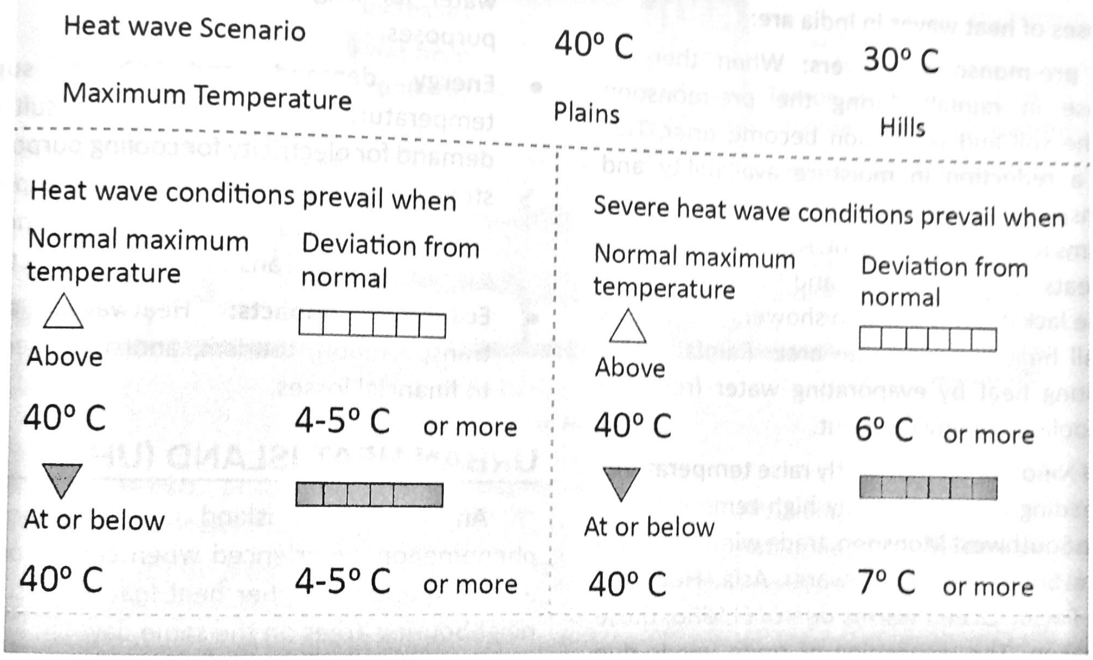
Statistics

- The 2015 heat wave in India, resulted in over 2,500 deaths and was one of the deadliest heat waves on record in the country.
- The 2018 heat wave in India, affected over 20 states and resulted in over 130 deaths.
- Between 1990 and 2019, the districts of Punjab, Haryana, Uttar Pradesh, Bihar, and Rajasthan in India have experienced an increase in summer temperatures ranging from 0.5°C to 0.9°C.
- Winter temperatures have increased in approximately 54% of India's districts.

Between the years 2021 and 2050, it is projected that the maximum temperature will increase by approximately 2-3.5°C in 100 districts and by 1.5-2°C in around 455 districts.

Indian Meteorological Department (IMD) criteria for heat waves

In India, a heatwave is typically defined as a period when the maximum temperature in a particular area reaches or exceeds 40 degrees Celsius for the Plains region, and at least 30 degrees Celsius for Hilly regions.



IMD Criteria for Heat Waves

Temperature

The terms "average maximum temperature," "normal maximum temperature," and "actual maximum temperature" refer to different concepts related to temperature measurements.

Average Maximum Temperature:

- The average maximum temperature is calculated by taking the average of the highest temperatures recorded over a specific period, such as a month or a year.
- It provides an indication of the typical or expected highest temperature within that time frame.
- It is often used to analyse long-term climate patterns and trends.

Normal Maximum Temperature:

- The normal maximum temperature, also known as the climatological maximum temperature, is a reference value that represents the average maximum temperature expected for a specific location during a particular period, such as a month or a season.
- It is typically based on long-term historical weather data, often spanning 30 years, and is updated periodically to reflect changes in climate patterns.
- The normal maximum temperature serves as a benchmark for comparison against current or future temperature observations to assess deviations from the expected climate.

Actual Maximum Temperature:

- The actual maximum temperature refers to the highest temperature recorded at a specific location during a particular day or time period.
- It represents the real-time or observed value of the highest temperature reached.
- Actual maximum temperatures can vary widely from day to day and are influenced by local weather conditions, such as solar radiation, cloud cover, humidity, and wind patterns.

Major causes of heat waves in India

India's geographical location and climate make it prone to heatwaves, especially during the summer months. The combination of clear skies, high solar radiation, and the absence of significant rainfall during this period contributes to the build-up of heat. Some of the major causes of heat waves in India are:

- **Reduced pre-monsoon showers:** When there is a decrease in rainfall during the pre-monsoon season, the soil and vegetation become drier. This leads to a reduction in moisture availability and evapotranspiration, which are important cooling mechanisms for the environment. As a result, the land surface heats up more quickly, and the air becomes hotter. The lack of pre-monsoon showers also affects the overall heat balance in an area. Rainfall helps in dissipating heat by evaporating water from the surface, cooling the environment.
- **El Nino:** El Niño events frequently raise temperatures in Asia, leading to exceptionally high temperatures. During the Southwest Monsoon, trade winds typically blow from South America towards Asia. However, when the Pacific Ocean warms due to El Niño, these winds weaken. The weakening of trade winds due to El Niño restricts the availability of moisture and heat content. This limitation in moisture and heat content leads to reduced and uneven distribution of rainfall across the Indian subcontinent, thus, creating conditions for heat waves in India.

Consequences of heat waves

Heat stress in India has significant impacts on various aspects of society, the economy, and public health. Here are some of the key impacts:

- **Human health:** Heat stress poses severe risks to human health. Heat-related illnesses, including heat exhaustion and heatstroke, are common in heatwaves. The extreme heat increases respiratory and cardiovascular problems and lead to dehydration and heat cramps.350 million Indians exposed to strong heat stress between April and May 2022.
- **Agricultural productivity:** Heat stress cause crop failures, reduced yields, and damage to livestock. It affects crop growth, pollination, and overall plant health.
- **Water resources:** Heatwaves and increased evaporation rates lead to increased demand for water for irrigation, domestic use, and industrial purposes.
- **Energy demand and power supply:** High temperatures during heatwaves result in increased demand for electricity for cooling purposes. This puts strain on the power grid, leading to power outage. Heat stress also affect the efficiency of power generation and transmission infrastructure.
- **Economic impacts:** Heatwaves also disrupt transportation, tourism, and other sectors, leading to financial losses.

URBAN HEAT ISLAND (UHI)

An urban heat island is a local and temporary phenomenon experienced when certain pockets within a city experience higher heat load than surrounding or neighbouring areas on the same day.

- The term "heat island" refers to the fact that cities and towns can be several degrees warmer than surrounding rural areas, creating a "**heat island**" effect.
- The variations are mainly due to heat remaining trapped within locations that often resemble concrete jungles. The temperature variation can range between 3 to 5 degrees Celsius.
- These temperature differences are due to variations in heating over highly urbanised and semi-urbanised areas and the comparative availability of open and green spaces in the surroundings.

Causes of Urban Heat Islands (UHIs)

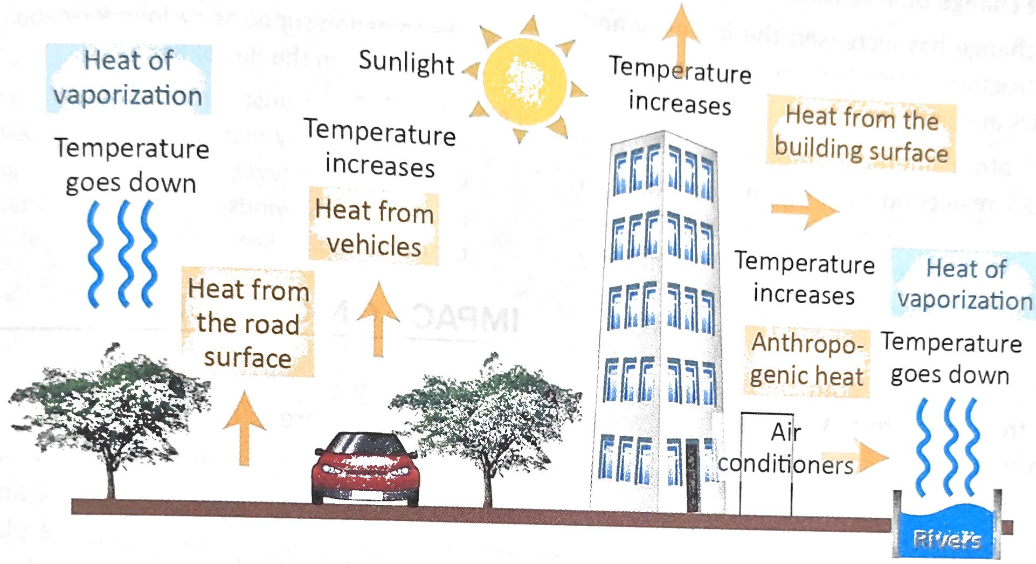
UHIs are caused by a variety of factors, including:

- **Human Activities:** The presence of buildings, roads, and other infrastructure can absorb and store heat from the sun, leading to increased temperatures.

- **Reduced Vegetation:** Urban areas often have fewer trees and green spaces, which can help to absorb and dissipate heat.
- **Lack of Airflow:** Buildings and other structures can block air flow, trapping heat and pollutants in urban areas.
- **Heat from Vehicles and Industry:** Cars, trucks, and other vehicles, as well as industrial activities, can release heat into the environment, contributing to UHIs.

Cities usually have buildings constructed with glass, bricks, cement and concrete — all of which are dark-coloured materials, meaning they attract and absorb higher heat content.

- **How the Heat Island Phenomenon occurs**



Urban Heat Island

Reasons why urban areas experience higher temperatures than rural areas:

- **Green coverage:** Rural areas typically have more green cover in the form of plantations, farmlands, forests, and trees compared to urban areas.
- **Transpiration** The transpiration process through which plants release water vapor, helps regulate temperatures in the surrounding environment.
- **Infrastructure:** Urban areas are more susceptible to the urban heat island effect due to factors such as frequent construction of high-rise structures, roads, parking spaces, pavements, and public transportation lines.
- **Concretisation:** The use of dark-coloured materials, such as black or dark-colored pavements and buildings made of glass, bricks, cement, and concrete, contributes to the absorption and retention of heat in urban areas.

Impact of Urban Heat Islands (UHIs):

- The impacts of UHIs can be significant, including increased energy consumption for cooling, decreased air quality, and negative health impacts, such as heat-related illnesses. Vulnerable populations, such as the elderly and those with respiratory illnesses, are particularly at risk.

What has NASA said on urban heat islands in India?

- NASA recently pointed out heat islands in urban parts of Delhi, where temperatures were far higher than nearby agricultural lands.
- NASA's Ecosystem Spaceborne Thermal Radiometer Experiment (Ecostress) captured an image which showed a large red patch around Delhi and smaller red patches around neighbouring cities of Sonipat, Panipat, Jind and Bhiwani.
- These red patches, implying higher temperatures, were the heat islands, while the rural areas around the cities witnessed lower temperatures.
- **Ecostress** is an instrument with a radiometer which was sent onto the International Space Station in 2018. It can measure temperatures on the ground, as opposed to the air temperature.

INTENSIFICATION OF STORMS

Storms are atmospheric disturbances characterized by strong winds, precipitation, and extreme weather conditions. They occur in various forms, including thunderstorms, snowstorms, hailstorms, tropical cyclones, hurricanes, typhoons, and tornadoes. Storms are typically associated with rapid changes in atmospheric pressure, temperature, humidity, and wind patterns.

Impact of climate change on intensification of storms:

The climate change has increased the intensity and frequency of destructive storms have across th planet in general and tropics in particular.

- **Increased atmospheric moisture:** Rising temperatures result in increased evaporation rates, leading to greater moisture content in the atmosphere. This increased moisture availability contributes to more severe storms.
- **Warmer sea surfaces:** The warming of the ocean has a direct influence on both the frequency and intensity of tropical storms. Warm surface waters in the ocean serve as the primary fuel for cyclones, hurricanes, and typhoons.
- **Changes in atmospheric circulation patterns:** Climate change disrupt atmospheric circulation patterns, such as the jet stream. Alterations in these patterns influence storm tracks, duration, and intensity.
- **Rising sea levels:** Climate change contributes to sea-level rise through the melting of glaciers and ice caps. Higher sea levels increase the risk of storm surges, which cause devastating coastal flooding during storms.

Warmer air contains more moisture, making tropical cyclones stronger, wetter, and capable of intensifying rapidly. In India, cyclones on the east coast are becoming a regular phenomenon; For instance, Cyclone Tauktae, Cyclone Yaas, Cyclone Fani etc.

Case Study: Increased frequencies in tropical cyclones in the Arabian Sea

The Arabian Sea previously experienced fewer extreme cyclones compared to the Bay of Bengal. Cyclones in the Arabian Sea can cause devastating storm waves and flooding upon landfall. The wind speed plays a role in the impact of cyclones. The enclosed shape of the Arabian Sea promotes evaporation and cloud formation.

- **Rising Sea Surface Temperatures:** Global warming has led to increased cyclone intensity due to higher seawater temperatures. The Arabian Sea experiences more cyclones due to rapid ocean warming.
- **Abundant Energy:** The warmer temperatures in the Arabian Sea provide ample energy to strengthen cyclones. Cyclone Tauktae intensified rapidly within 2 days due to warm seawater up to 50 meters deep.
- **Wind Gradient:** The Arabian Sea creates favourable wind shear or wind gradients for cyclone formation. The easterly winds at higher altitudes pushed Cyclone Ockhi from the Bay of Bengal to the Arabian Sea.
- **El Nino Modoki Climatic Phenomenon:** The increased occurrence of El Nino Modoki contributes to the intensified cyclones in the Arabian Sea. This climatic phenomenon supports cyclone formation in the Arabian Sea but not in the Bay of Bengal.
- **Aerosol Emissions:** Anthropogenic aerosol emissions have significantly increased since 1930.These emissions weaken upper-level easterly winds and lower-level south-westerly winds, affecting precipitation movement over the Arabian Sea.

IMPACT ON CRYOSPHERE

Cryosphere

The cryosphere is the portion of the Earth's surface where water exists in a solid form, including snow, ice caps, glaciers, frozen lakes and rivers, and permafrost. It plays a crucial role in regulating the planet's climate, reflecting sunlight back into space and affecting ocean circulation patterns. The cryosphere is very sensitive to climate change and is currently undergoing rapid changes due to global warming, with significant implications for sea level rise, freshwater availability, and ecosystem functioning.

According to the Intergovernmental Panel on Climate Change (IPCC), the cryosphere covers about 10% of the Earth's surface.

Importance of Cryosphere

The cryosphere is a critical component of the Earth's climate system and plays several important roles:

- **Climate regulation:** The cryosphere helps regulate the Earth's climate by reflecting sunlight back into space, which helps cool the planet. This is particularly important in high-latitude regions where snow and ice cover are more prevalent.
- **Sea level rise:** The cryosphere holds a significant amount of the Earth's freshwater, and as it melts, it contributes to sea level rise. This has implications for coastal cities and communities around the world.
- **Freshwater availability:** The cryosphere also serves as a source of freshwater for many regions, particularly during the summer months when other sources may be scarce.

- **Ecosystem functioning:** The cryosphere provides habitat for many species, including polar bears, penguins, and Arctic and Antarctic fish and mammals. Changes in the cryosphere can have significant impacts on these ecosystems.
- **Natural resources:** The cryosphere contains valuable natural resources, such as oil and gas, minerals, and freshwater. As the cryosphere melts, these resources may become more accessible, but their extraction can also have negative environmental consequences.

Impact of climate change on Cryosphere

The cryosphere is highly sensitive to changes in the Earth's climate, and the effects of climate change on the cryosphere are already being observed. The effects of climate change are most pronounced in the world's coldest regions, such as the poles. :

- **Thinning Arctic Sea ice:** The extent of Arctic sea ice has been decreasing at an unprecedented rate in recent years, with the thickness of the ice decreasing as well. As per studies, the Arctic could be ice-free in the summer within the next 15 years.
- **Permafrost thaw:** Permafrost, which is frozen soil that covers much of the Arctic, is beginning to thaw due to warming temperatures. As it thaws, it releases large amounts of carbon dioxide and methane, which can further contribute to global warming.
- **Changes in freshwater availability:** As glaciers and ice caps melt, they are changing the availability of freshwater in many regions of the world, with implications for agriculture, industry, and human populations.
- **Impacts on wildlife:** The rapid changes in the cryosphere are having significant impacts on wildlife that rely on ice and snow for their survival, such as polar bears, penguins, and Arctic and Antarctic fish and mammals.

Karakoram Anomaly

- The Karakoram Anomaly refers to an area in the Karakoram mountain range where glaciers have not experienced significant melting despite global warming. This is in contrast to the majority of glaciers in other parts of the world, which have been rapidly melting due to rising temperatures.

Why is the Karakoram Range Resisting Glacial Melt?

- Since the beginning of the century, the Western disturbance (WD) has played a crucial role in initiating and sustaining the Karakoram Anomaly.
- The region heavily relies on western disturbance to provide snowfall during winters. Recent studies suggest that the contribution of western disturbance to snowfall in the core glacier areas of the Karakoram has increased by about 27%.
- Moreover, the precipitation intensity of western disturbance affecting the Karakoram has also risen by approximately 10% in the last two decades, further emphasizing their importance in maintaining the regional anomaly.

Arctic Amplification

- The Arctic experiences a phenomenon known as Arctic amplification, resulting in it warming 2-3 times faster than the global rate, due to unique features in its climate system.
- Recent study findings reveal that the Arctic is warming even faster than previously thought. The Arctic is now heating up 4 times faster than the rest of the planet, with the warming being more concentrated in the Eurasian region.
- Specifically, the Barents Sea, north of Russia and Norway, is experiencing an alarming rate of warming, increasing at a rate that is 7 times faster than the global average.
- Furthermore, even the best climate models may not be sufficient to accurately capture the rate and extent of change in the Arctic region.

Link Between Fast-Melting Arctic Ice and Ocean Acidification

- The researchers have identified a significant shift in the chemical makeup of the western Arctic Ocean. The team observed that the acidity levels in this region are increasing at a rate 3-4 times faster than in other parts of the ocean.
- They have also established a clear link between the accelerated melting of ice and the rate of ocean acidification.

Step by India to Minimise the Impact of Arctic Amplification

- Himadri Research Centre, established in July 2008 in the Arctic, conducts various studies on meteorology, biology, glaciology, and past climate.
- India's first moored-underwater observatory, called IndARC, was deployed in 2014 to monitor the effect of Arctic Ocean changes on tropical processes such as the monsoons.
- India's Arctic Policy, launched by the Ministry of Earth Sciences, focuses on improving analysis, forecasting, and coordinated policy making on the impact of melting ice in the Arctic.

Melting sea ice

Melting sea ice refers to the process of ice in the polar regions, specifically the Arctic and Antarctic, transitioning from solid ice to liquid water due to rising temperatures.

Impact of climate change on melting sea ice

Climate change is causing the melting of sea ice in polar regions, particularly in the Arctic and Antarctic. Here are some key effects of climate change on melting sea ice:

- **Rising sea levels:** Melting Sea ice, unlike land-based ice, does not directly contribute to sea-level rise since it is already in the water. However, as ice on land (such as glaciers and ice sheets) melts, it adds water to the oceans, causing sea levels to rise. This rise in sea levels, in turn, have far-reaching impacts on coastal communities and ecosystems.
- **Melting glaciers and ice caps:** Glaciers and ice caps around the world are melting at an accelerating rate due to rising temperatures, causing sea levels to rise and leading to increased flooding in coastal areas. The Arctic is heating up twice as fast as any other place on Earth, causing the rapid melting of glaciers and polar ice sheets, which store a large amount of water.
- **Feedback loops:** Melting sea ice contributes to a **positive feedback loop** known as the **ice-albedo feedback**. As sea ice melts, more dark ocean surface is exposed, which absorbs more sunlight and increases warming, leading to further ice melt.
- **Disrupted ecosystems:** The loss of sea ice affects marine ecosystems, as many organisms depend on ice as a habitat or food source. Polar bears, seals, walruses, and other ice-dependent species are facing challenges in finding suitable habitat and food due to melting sea ice.
- **Altered ocean circulation:** The melting of sea ice affect ocean currents and circulation patterns. Changes in ocean circulation influence climate patterns, weather systems, and the distribution of heat around the globe.

IMPACT ON SEA LEVEL

Climate change has a significant impact on sea level rise, primarily through two mechanisms: thermal expansion of seawater and the melting of land-based ice. Sea level rise is putting coastal countries at risk. For example, according to a study, almost 80% of the Maldives could become uninhabitable by 2050, at current global warming rates.

Impact of climate change on rising sea levels

- **Thermal expansion:** As the Earth's atmosphere and oceans warm due to increasing greenhouse gas concentrations, the water in the oceans expands. This thermal expansion contributes to a sea level rise. Melting sea ice and glaciers and the expansion of warmer water could cause sea levels to rise by up to 3.61 feet by the end of the century if emissions are not reduced. This is already affecting countries like Bangladesh, where one-quarter of the land lies less than 7 feet above sea level.
- **Melting of glaciers and ice caps:** Climate change is causing the melting of glaciers and ice caps around the world, including Greenland and Antarctica.
- **Changes in land-based water storage:** Climate change affect the distribution of water on land. The meltwater from land-based ice sources flows into the oceans, contributing to sea level rise. For instance, the increased melting of mountain snowpacks and changes in precipitation patterns alter the amount of water stored on land. When this water eventually reaches the ocean, it adds to sea level rise.
- **Coastal erosion and inundation:** Rising sea levels increase coastal erosion and increase the risk of coastal flooding and inundation. Low-lying areas, including coastal cities and islands, are particularly vulnerable to the impacts of sea level rise, leading to the loss of land, infrastructure, and displacement of populations. A rise of even just one foot by 2050 could damage infrastructure, erode beaches, and harm the environment by encroaching on coastal ecosystems and freshwater aquifers used for agriculture and drinking water.
- **Impacts on ecosystems and biodiversity:** Rising sea levels affect coastal ecosystems, including mangroves, salt marshes, and coral reefs, which provide important habitats and protect coastlines from erosion.

FLOODS AND DROUGHT

As Earth's climate continues to warm, changes in rainfall patterns, rising sea levels, and altered weather dynamics have resulted in a heightened risk of devastating floods and prolonged droughts.

Floods

- **Increased Intensity:** Climate change lead to more intense rainfall events, resulting in an increased flooding. Warmer temperatures enhance evaporation rates, which, in turn, lead to more moisture in the atmosphere. This increased moisture is released as heavy precipitation during storms, leading to flash floods and river flooding. For instance, the Mumbai floods of 2005, the Chennai floods of 2015, the Kerala floods of 2018, and the Assam floods of 2020.

- **Sea-Level Rise:** As mentioned earlier, climate change contributes to rising sea levels. Higher sea levels elevate the baseline for storm surges and tidal flooding, amplifying the impacts of coastal flooding during extreme weather events.
- **Changes in Rainfall Patterns:** Climate change also cause shifts in rainfall patterns, leading to changes in the timing and distribution of precipitation. Some regions experience more frequent and intense rainfall events, while others see a decrease in overall precipitation. These changes contribute to both localized and riverine flooding. For instance, deadly flooding in Pakistan was caused by a combination of heavy rains and melting glaciers and snow in 2022.

Droughts

- **Increased Frequency and Duration:** Climate change increase drought conditions in certain regions. Rising temperatures enhance evaporation rates, leading to increased water loss from soils and vegetation. This result in extended periods of reduced soil moisture and lower water availability, leading to more frequent and prolonged droughts. For instance, the 2015-2016 drought in India, which affected over 330 million people and led to crop failures, water shortages, and widespread food insecurity.
- **Changes in Precipitation Patterns**: Climate change alter precipitation patterns, resulting in shifts in rainfall distribution. Some areas experience reduced rainfall, while others may receive more sporadic and intense precipitation events. These changes contribute to drought conditions by reducing water availability and increasing water stress for agriculture, ecosystems, and communities.
- **Impacts on Water Resources:** Droughts impact water resources, such as rivers, lakes, and groundwater reserves. Reduced water availability strain water supplies for agriculture, industry, and domestic use, leading to water scarcity and conflicts over resources.

IMPACT ON OCEANS

Climate change has profound impacts on the Earth's oceans, altering their temperature, chemistry, circulation patterns, and ecosystems.

Impact of climate change on oceans

- **Ocean Warming:** The increase in greenhouse gas emissions, particularly carbon dioxide, leads to the trapping of heat in the atmosphere. A significant portion of this trapped heat is absorbed by the oceans, resulting in ocean warming. Warmer waters can have far-reaching consequences, including coral bleaching, species migrations, changes in productivity, and shifts in marine habitats. For instance, oceans absorb 93 percent of all the heat that's trapped by greenhouse gases and up to 30 percent of all the carbon dioxide emitted from burning fossil fuels.
- **Changes in Ocean Circulation:** Climate change disrupt global ocean currents, such as the **Atlantic Meridional Overturning Circulation (AMOC)**, which plays a crucial role in redistributing heat around the globe. Alterations in ocean circulation patterns affect regional climates, sea surface temperatures, and precipitation patterns, potentially leading to more extreme weather events and impacting marine ecosystems and fisheries.
- **Loss of Marine Biodiversity:** Climate change poses a significant threat to marine biodiversity. Warming waters cause the migration of species toward cooler regions, disrupting ecosystems and altering species interactions. For instance, Coral reefs, known as the rainforests of the sea, are particularly vulnerable to climate change, with rising temperatures leading to widespread coral bleaching events and the degradation of these diverse and valuable ecosystems. Temperature-sensitive fish and other marine life are already changing migration patterns toward cooler and deeper waters to survive.

Case Study: Marine Heat Wave in India

An underwater survey showed that 85% of the corals in Gulf of Mannar near the Tamil Nadu coast got bleached after the marine heatwave in May 2020.

- Marine heatwaves in the western Indian Ocean could also mean that weak monsoon winds reach the central Indian subcontinent — the core monsoon zone and the rain-fed agriculture belt.
- Furthermore, El Nino — the phenomenon of abnormal warming along the central and equatorial Pacific Ocean — too was a contributor to the increasing frequency and intensity of marine heat waves along the Indian Ocean Region.
- These changes are in response to the modulation of the monsoon winds by the heatwaves.

This is the first time that a study has demonstrated a close link between marine heatwaves and atmospheric circulation and rainfall.

Oceanic Acidification

Ocean acidification refers to a reduction in the pH (Increasing acidic nature) of the ocean over an extended period of time. caused primarily by uptake of carbon dioxide from the atmosphere.

For millions of years, the exchange of carbon dioxide between the surface of the ocean and the atmosphere remained constant. The ocean is slightly basic. Prior to the Industrial Revolution of the 18th to 19th centuries, the ocean's average pH was about 8.2. In the past 150 years, humans have greatly increased the amount of carbon dioxide in the atmosphere by burning fossil fuels and changing land-use practices. Currently the ocean's average pH is 8.1. Additionally, the ocean currently is about 30 per cent more acidic than in pre-industrial times.

According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, by 2100 AD, the pH of the ocean could decrease to about 7.8. This will make the ocean 150 percent more acidic and affecting half of all marine life.

Evidences of Ocean Acidification

There is strong scientific evidence of ocean acidification and its impacts on the world's oceans. Some of the key evidence includes:

- **Declining pH:** Measured Ocean pH values have shown a consistent decrease over the last century, with a decrease of approximately 0.1 units, indicating a 30% increase in acidity.
- **Dissolving Shells:** Observations of declining shell and skeleton growth in some species of marine organisms, such as corals, molluscs, and some species of plankton, provide clear evidence of the impacts of ocean acidification on calcifying organisms.
- **Changes in Marine Ecosystems:** Changes in the distribution and abundance of some species of marine life, as well as shifts in the structure of marine food webs, suggest that ocean acidification is altering the functioning of marine ecosystems.
- **Model Predictions:** Computer models that simulate the impacts of ocean acidification on the world's oceans have consistently predicted declines in pH and the availability of carbonate ions, as well as changes in marine ecosystems, fisheries, and biodiversity.

Ocean acidification and Temperature

The rising concentration of carbon dioxide in the atmosphere is driving up ocean surface temperatures and causing ocean acidification. Although warming and acidification are different phenomena, they interact to the detriment of marine ecosystems.

- The rate at which water absorbs carbon dioxide decreases as water temperature increases.
- This means that polar regions like Alaska, where ocean water is relatively cold, can take up more carbon dioxide than the warmer tropics.
- As a result, polar surface waters are generally acidifying faster than those in other latitudes.

Process of Ocean Acidification

Ocean acidification is a process that occurs when carbon dioxide from the atmosphere dissolves in seawater, leading to a decrease in pH and an increase in acidity. The process of ocean acidification can be described as follows:

- **Release of carbon dioxide:** The burning of fossil fuels, deforestation, and other human activities result in the release of large amounts of carbon dioxide into the atmosphere.
- **Absorption of carbon dioxide:** Approximately a quarter of the carbon dioxide released into the atmosphere is absorbed by the ocean.
- **Formation of carbonic acid:** When carbon dioxide enters the ocean, it dissolves in saltwater. First, it forms carbonic acid. Then, carbonic acid , a weak acid that breaks (or "dissociates") into hydrogen ions and bicarbonate ions.
- **Decreased pH:** Ocean acidification results from an increased concentration of hydrogen ions and a reduction in carbonate ions due to the absorption of increased amounts of carbon dioxide. Clams, mussels, crabs, corals, and other sea life rely on carbonate ions to grow their shells and thrive.

Causes Ocean Acidification

Ocean acidification is mainly caused by carbon dioxide gas in the atmosphere dissolving into the ocean. This leads to a lowering of the water's pH, making the ocean more acidic. The following factors are responsible for large emission of carbon dioxide:

Anthropogenic factors	Natural Factors
• The burning of fossil fuels such as coal, oil and gas for human industry is one of the major causes. • Deforestation results in fewer trees to absorb the carbon dioxide gas. • When plants are cut down and burnt or left to rot, the carbon that makes up their organic tissue is released as carbon dioxide.	• Some parts of the ocean are naturally acidic, such as at hydrothermal vent sites - underwater 'hot springs'.

Ocean Acidification in India:

Ocean acidification is also affecting the Indian Ocean, and the impacts are being felt in India and its surrounding countries.

India's coral reefs, which are important habitats for marine life and support important fisheries, are being threatened by ocean acidification.

Impact of Ocean acidification

Climate change and ocean acidification are two interconnected processes that are both caused by the increased concentration of carbon dioxide in the atmosphere. As humans continue to burn fossil fuels, more and more carbon dioxide is emitted into the atmosphere, which leads to a warming of the planet and a change in the chemical composition of the ocean. The oceans are a natural sink for carbon dioxide. When carbon dioxide dissolves in seawater, it forms carbonic acid, which reduces the pH of the ocean which ultimately leads to Oceanic Acidification.

Coastal and marine ecosystems are under tremendous stress from climate change. Ocean acidification, paired up with other climate impacts like warming waters, deoxygenation, melting ice, and coastal erosion, pose real threats to the survival of many marine species. Some of the key impacts of Ocean acidification include:

- **Threat to Marine Biodiversity:** Acidification reduces the availability of carbonate ions in ocean water. These carbonate ions provide the building blocks for these organisms to make their shells and skeletons. Ocean acidification can reduce the ability of marine organisms (corals, mollusks, and some species of plankton) to form and maintain their shells and skeletons. For instance, Coral Bleaching (Australia's Great Barrier Reef has shown a 14 percent decline in calcification since 1990). However, The growth of those species whose photosynthesis was limited by carbon dioxide will be increased in enhanced carbon dioxide situations. For instance, a strong increase in photosynthesis rates was reported for cyanobacteria under higher carbon dioxide concentrations.

- **Effects on Fisheries:** The productivity and distribution of some commercially important fish species (such as Pacific salmon and Atlantic cod) may be affected by ocean acidification. Consequently, reducing the availability of fish species for human consumption.
- **Impacts on Marine Mammals:** The decline in the populations of key prey species, such as krill, may affect the survival and reproduction of some marine mammals, such as whales and seals.
- **Changes in Ocean Circulation:** The acidification of the ocean can alter the balance of seawater chemistry and affect ocean circulation patterns, potentially affecting global climate patterns.
- **Economic Impacts:** The impacts of ocean acidification on commercial fisheries, tourism, and other industries dependent on the ocean can result in significant economic losses.
- **Threat to Food Security:** The decline in the populations of some species of marine life and changes in the structure of marine food webs can reduce the availability of food for human consumption and threaten food security in coastal communities.

IMPACT ON LAND-BASED ECOSYSTEMS

Climate change has significant impacts on land-based ecosystems, including forests, grasslands, and wetlands.

Forests

- **Increased Forest Mortality:** Rising temperatures and changing precipitation patterns lead to increased stress on forest ecosystems. Droughts and heatwaves cause water stress and reduced tree growth, making forests more susceptible to pests, diseases, and wildfires. These factors result in increased forest mortality rates and shifts in species composition.
- **Altered Forest Distribution:** As temperatures rise, some tree species face challenges adapting to new climatic conditions. Many species are moving towards higher elevations or latitudes in search of suitable habitats, causing shifts in the geographic distribution of forests. This results in changes in forest composition and ecosystem dynamics, leading to the loss of unique and specialized forest types.
- **Increased Wildfire Risk:** Climate change contributes to drier conditions and longer fire seasons in many regions. Hotter and drier conditions promote the occurrence of wildfires, which lead to widespread forest destruction.
- **Changes in Forest Productivity:** Climate change affect forest productivity by altering the length and timing of the growing season. Warming temperatures advance budburst and flowering, potentially leading to phenological mismatches with pollinators or disrupt trophic interactions.
- **Impacts on Biodiversity:** Forests are home to a vast array of plant and animal species, and climate change poses a threat to their biodiversity. As forests experience shifts in temperature and precipitation, some species may struggle to adapt or migrate to suitable habitats. This lead to changes in species composition, disruptions in ecological interactions, and potential loss of biodiversity.
- **Carbon Storage:** Climate change disrupt this important carbon sink. Increased forest mortality, wildfires, and disturbances from pests and diseases release carbon stored in trees and soil, contributing to higher greenhouse gas emissions and further amplifying climate change.

Grasslands

- **Altered Precipitation Patterns:** Climate change disrupt precipitation patterns in grassland regions. This affects the plant productivity, soil moisture levels, and water availability, affecting the composition and functioning of grassland ecosystems.
- **Shifts in Vegetation Composition:** Changing climate conditions lead to shifts in the distribution and abundance of plant species in grasslands. Certain species become more dominant, while others struggle to adapt to new climatic conditions. This alters the grazing patterns, and affect the overall biodiversity and ecological stability of grassland habitats.
- **Increased Drought Stress:** Rising temperatures associated with climate change increase drought conditions in grasslands. Drought stress lead to decreased plant growth, reduced forage availability for grazing animals, and increased vulnerability to wildfires.
- **Altered Fire Regimes:** Grasslands are fire-adapted ecosystems, and fire plays a crucial role in their maintenance and renewal. However, climate change influence fire regimes in grasslands. Drier conditions, combined with changes in precipitation patterns, increase the frequency and intensity of wildfires.

Wetlands

Altered water flow and increasing temperatures affect the chemistry and functioning of wetlands. These changes impact the wetland's ability to provide services such as water purification.

- The breakdown of organic matter and release of nutrients into the water are consequences of these changes.
- If decomposition outpaces plant growth, wetlands shift from storing carbon to releasing carbon.
- Climate change may cause constructed wetlands and peatlands to release carbon instead of storing it.
- Loss of wetlands results in the loss of habitats for migratory birds, with over 85% of wetlands lost since 1700.
- Higher temperatures accompanied by increased precipitation can promote plant growth and photosynthesis.
- This balance offsets carbon release, allowing wetlands to continue acting as carbon sinks.

IMPACT ON ANIMALS

Climate change is having significant impacts on animals, disrupting their habitats, altering their behaviour, and threatening their survival. As the Earth's climate system undergoes rapid changes, animal species around the world are facing numerous challenges that can have far-reaching consequences for biodiversity and ecosystem functioning.

- **Habitat Loss and Fragmentation:** Rising temperatures, altered precipitation patterns, and changes in vegetation lead to the loss and fragmentation of animal habitats. Many species have specific habitat requirements, and when their habitats shrink or become unsuitable, it results in reduced population sizes and limited access to resources necessary for their survival. For instance, ice-dependent mammals like walruses and penguins who are impacted by shrinking ice sheets.
- **Altered Phenology and Breeding Patterns:** Climate change disrupt the timing of critical biological events, such as breeding, migration, and hibernation. Changes in temperature and precipitation affect food availability and vegetation phenology, leading to mismatches between the timing of these events and optimal conditions. This impact reproductive success, survival rates, and population dynamics of many animal species.
- **Increased Extinction Risk:** Climate change poses a significant threat to animal species, particularly those that are already vulnerable or have specialized habitat or dietary requirements. Rapid shifts in climatic conditions outpace the ability of species to adapt, potentially leading to population declines and increased risk of extinction.
- **Ocean Acidification and Coral Bleaching:** Increasing carbon dioxide levels in the atmosphere lead to ocean acidification, negatively impacting marine ecosystems. Acidic waters affect the growth and survival of shell-forming organisms, such as corals, mollusks, and some planktonic species. Coral bleaching, driven by increased water temperatures, result in the loss of coral reefs, impacting the biodiversity and productivity of marine habitats and the species that depend on them.
- **Disruption of Ecological Interactions:** Climate change disrupt intricate ecological interactions between species. For example, changes in the timing of plant flowering affect the availability of nectar for pollinators, potentially impacting pollination services and the reproduction of both plant and animal species. Disruptions in predator-prey relationships and food web dynamics have cascading effects throughout ecosystems.

Case study: Extinction of Polar Bears

The zoological name of **polar bears** is **Ursus Maritimus** meaning **"Sea Bear"**. The polar bears are only found in the Arctic regions where the temperature can go as low as -50 degrees Celsius. Over 40% of polar bears are found in the northern parts of Canada. Polar bears are the largest land carnivores.

Statistics

- According to a recent survey conducted in 2021 by air, researchers estimated that there were 618 polar bears remaining in Western Hudson Bay (Northeastern canada), which comprises the renowned town of Churchill, often referred to as **'the Polar Bear Capital of the World'**.

- In the previous survey conducted in 2016, the number of polar bears recorded in the same area was 842.
- A study published in the scientific journal Nature Climate Change in 2020 projected that polar bears would face extinction by the end of this century.

Why is the existence of polar bear so important?

- Polar bears play a crucial role as top predators in the Arctic, contributing to the balance of biological populations.
- Their significant kills act as a valuable food resource for scavengers such as Arctic foxes and Arctic birds.
- If polar bears are unable to hunt their primary prey, such as seals, it can have severe consequences on the food chain and overall ecosystem health.
- Researchers have observed that when polar bears struggle to find seals, they may resort to hunting and relying on other Arctic creatures for survival.
- This could pose a threat to the existence of species like the Arctic fox and the walrus.
- Additionally, it could lead to the overpopulation of seals, which in turn could jeopardize the survival of crustaceans and fish, important food sources for local human populations and other Arctic wildlife.

How will climate change lead to extinction of polar bears?

- The survival of polar bears heavily relies on the presence of Arctic Sea ice, which serves multiple purposes such as hunting seals (their primary food source), traveling, mating, and resting.
- However, the increasing global temperatures have led to the early breakup and delayed formation of sea ice during summer and winter seasons. As a result, polar bears have a reduced hunting period, longer periods of hunger, and the need to travel longer distances.
- This increased energy demand, combined with limited food availability, can lead to physical deterioration and a decrease in the average weight of adult polar bears.
- A study published in 2020 revealed that rising temperatures and diminishing ice can result in female polar bears giving birth to smaller litters of cubs.
- Additionally, the decline in sea ice can pose a threat to the stability of dens that polar bears construct for birthing and protecting their young, potentially leading to their collapse.

ECONOMIC IMPACT OF CLIMATE CHANGE

The economic impact of climate change refers to the effects that climate change has on various sectors of the economy and overall economic well-being. Climate change, driven primarily by human activities and the release of greenhouse gases, is altering the Earth's climate system and leading to a range of environmental changes. These changes, in turn, have far-reaching economic consequences that affect industries, infrastructure, agriculture, natural resources, and overall economic stability.

- **Cost of Natural Disasters:** Climate change is associated with an increase in the frequency and intensity of extreme weather events, such as cyclones, floods, droughts, and wildfires. These disasters cause extensive damage to infrastructure, property, and agriculture, resulting in substantial economic losses. Rebuilding and recovery efforts impose financial burdens. For instance, the 2018 National Climate Assessment predicts that climate change will cost the Indian economy up to $500 billion annually by the end of the century, excluding its effect on human health.
- **Water Resources:** Climate change affects the availability and quality of water resources, which are essential for various sectors, including agriculture, industry, and domestic use. Thus, impacting industries, energy generation, and overall economic development.
- **Tourism**: Rising sea levels and increased storm surges pose risks to coastal infrastructure, including cities, ports, and tourism facilities. For instance, coastal tourism, a major source of revenue for many countries, it is impacted by the loss of beaches, coral reefs, and other natural attractions.
- **Energy and Infrastructure:** Climate change impacts energy systems and infrastructure. Changes in temperature patterns affect energy demand, while extreme weather events damage energy infrastructure, disrupt power supply, and increase the risk of blackouts.
- **Health and Healthcare Costs:** Climate change affect human health, leading to increased healthcare costs. Heatwaves, infectious diseases, air pollution, and mental health issues are some of the health-related impacts associated with climate change.

Impact on agriculture

Climate change has emerged as a major threat to global agriculture, posing significant challenges to food production, farmer livelihoods, and overall food security.

- **Changing Growing Seasons:** Climate change alters temperature and precipitation patterns, leading to shifts in growing seasons. This disrupts planting and harvesting schedules, affecting crop yields and quality.
- **Water Availability:** Changes in precipitation patterns and increased evaporation lead to water scarcity, particularly in regions dependent on rainfall for irrigation. Droughts reduce crop yields, impair livestock production, and increase the risk of wildfires.
- **Crop Yields and Nutritional Content:** Rising temperatures, heatwaves, and extreme weather events negatively impact crop yields. Heat stress reduce photosynthesis and affect pollination, leading to lower productivity.
- **Pest and Disease Pressure:** Climate change influence the distribution, abundance, and life cycles of pests and diseases. Warmer temperatures and altered rainfall patterns favor the proliferation of certain pests, leading to increased crop damage.
- **Livestock and Animal Agriculture:** Heat stress affects livestock health, productivity, and reproduction. Increased temperatures reduce feed intake, impair milk production, and increase susceptibility to diseases.
- **Reduced soil health:** Healthy soil is essential for healthy crops and is characterized by good moisture and mineral content, and a diverse population of bugs, bacteria, fungi, and microbes. However, climate change, especially extreme heat and changes in precipitation patterns, can negatively impact soil quality. This problem is worsened in areas where industrial, chemical-dependent monoculture farming has depleted the soil's natural resilience, making it more vulnerable to environmental changes.

Impact on industries

Climate change has a significant impact on various industries across the globe. Here are some key areas where industries are affected:

- **Agro based industry:** Climate change disrupt agricultural systems through changes in temperature, precipitation patterns, and extreme weather events. Shifts in growing seasons, water availability, and increased pest and disease pressures impact crop yields and livestock production. This affects food security, supply chains, and prices.
- **Energy:** Climate change influences the energy sector in multiple ways. The increased frequency and intensity of extreme weather events, such as cyclones damage energy infrastructure, including power plants, transmission lines, and oil and gas facilities. Additionally, the transition to low-carbon energy sources, such as renewable energy, is driven by the need to mitigate climate change.
- **Tourism and Hospitality industry:** Climate change alter travel patterns and destination attractiveness. Rising temperatures, changing weather patterns, and the loss of iconic landscapes, such as coral reefs and glaciers, impact tourism activities like beach tourism, skiing, and ecotourism.
- **Manufacturing and Supply Chains:** Climate change disrupts global supply chains by affecting transportation routes, availability of raw materials, and production processes. Extreme weather events cause physical damage to manufacturing facilities, interrupt production, and impact distribution networks.
- **Water and Natural Resources:** Climate change affects water availability, quality, and distribution. Industries reliant on water resources, such as agriculture, energy, manufacturing, and mining, face challenges due to changing precipitation patterns, droughts, and increased competition for water resources.
- **Construction and Infrastructure:** Climate change influences building design and infrastructure development. Rising temperatures and changing weather patterns require resilient infrastructure to withstand extreme events like heatwaves, floods, and storms.

Impact on fishing

Climate change has significant impacts on fishing and the overall health and productivity of marine ecosystems. These impacts are felt by both commercial and subsistence fishermen and have far-reaching consequences for coastal communities and global food security.

- **Changes in Fish Distribution:** Rising ocean temperatures and changing currents alter the distribution patterns of fish species. As waters warm, some fish species migrate to cooler regions or deeper waters, impacting the availability of traditional fishing grounds. This disrupts fishing communities' livelihoods and traditional fishing practices.

- **Ocean Acidification:** Increased carbon dioxide levels in the atmosphere due to climate change are absorbed by the oceans, leading to ocean acidification. Acidic waters negatively affect shellfish and other marine organisms with calcium carbonate shells or skeletons, impairing their growth and survival. This have cascading effects throughout the food chain, impacting fish populations and the fishing industry.
- **Coral Reef Degradation:** Climate change-induced ocean warming and coral bleaching events cause the degradation and loss of coral reef ecosystems. Coral reefs provide critical habitats for many fish species, supporting their reproduction, growth, and overall abundance. When coral reefs decline, fish populations that rely on these ecosystems for food and shelter are negatively affected, leading to reduced fish stocks and impacts on fishing activities.
- **Altered Productivity and Fishery Cycles:** Climate change disrupt the timing and productivity of fishery cycles. Changes in water temperature, nutrient availability, and the timing of phytoplankton blooms impact the reproductive patterns and feeding behaviours of fish species. This affect fishery yields, making it challenging for fishermen to predict and respond to seasonal variations in fish populations.

Impact on human health

Climate change has significant impacts on human health, both direct and indirect, through various pathways. These impacts are projected to worsen with continued global warming. Some of the key health impacts of climate change include. According to the World Bank estimates, climate change could cause an additional 250,000 deaths per year due to malnutrition, disease, and heat stress. If action is not taken, global leaders predict a catastrophic 4.3 degrees Celsius of warming by the end of the century, which could lead to wars over water, overcrowded hospitals, and other devastating consequences.

- **Heat-related Illnesses and Deaths:** Rising temperatures increase the frequency, duration, and intensity of heatwaves, leading to heat-related illnesses such as heat exhaustion and heatstroke. Heatwaves also increase existing cardiovascular and respiratory condition. For instance, a 2-degree Celsius rise in temperature could put 1 billion people at risk of heat stress. Some other instances like, in the summer of 2022 alone, thousands died in record-shattering heat waves across Europe. Weeks later, dozens were killed by record-breaking urban flooding in the United States and Korea. While more than 1500 people perished in the flooding in Pakistan
- **Increased Disease Burden:** Climate change affects the distribution and transmission of certain diseases. Warmer temperatures and changing precipitation patterns expand the geographical range of vector-borne diseases like malaria, zika, dengue fever, and Lyme disease. For instance, between 2030 and 2050, climate change is expected to cause approximately 250 000 additional deaths per year, from malnutrition, malaria, diarrhea and heat stress.
- **Air Pollution and Respiratory Issues:** Climate change worsen air quality, leading to increased respiratory problems. Higher temperatures and increased ground-level ozone formation worsen smog and contribute to respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD).
- **Mental Health Impacts:** Climate change-related events, such as natural disasters and prolonged extreme weather events, cause psychological distress and have long-term impacts on mental health. Displacement, loss of homes, and community disruption due to climate-related disasters lead to anxiety, depression, post-traumatic stress disorder (PTSD), and other mental health disorders. For instance, 45% of young people from 10 countries reporting that their feelings about climate change affect their daily lives.

SOCIAL IMPACT OF CLIMATE CHANGE

The social impact of climate change refers to the effects that climate change has on societies, communities, and individuals. Climate change, driven by human activities and the release of greenhouse gases, is altering the Earth's climate system and leading to a range of environmental changes. These changes have far-reaching social consequences that affect people's well-being, livelihoods, and the overall fabric of societies.

- **Worsening inequity:** The climate crisis disproportionately affects developing countries and worsens existing inequalities, especially for resource-constrained populations. Developed nations, responsible for most greenhouse gas emissions, will face less severe consequences compared to developing nations. Within countries, disparities will widen as those with more resources can better cope with climate change impacts, while marginalized communities face greater vulnerability.

- **Climate refugees:** Climate refugees, also known as environmental migrants or climate-induced displaced persons, are individuals or communities who are forced to leave their homes or homeland due to the impacts of climate change. Climate change causes displacement due to factors like scarcity of food and water, sea level rise, and economic instability. This is already happening, as recognized by the United Nations Global Compact on Refugees. According to the Internal Displacement Monitoring Centre's (IDMC) report, 23.7 million people experienced displacements in 2021 as a result of cyclones and floods. The World Bank estimates that up to 140 million people could be displaced within their home countries by 2050.
- **Social Cohesion and Conflict:** Climate change strain social cohesion and increase the potential for conflicts. Resource scarcity, competition for water and land, displacement, and economic disruptions contribute to social tensions and increases existing conflicts.
- **Cultural and Indigenous Impacts:** Climate change threatens cultural heritage, traditional practices, and indigenous knowledge systems. Changes in ecosystems, loss of biodiversity, and shifts in migration patterns of flora and fauna disrupt the relationship between indigenous communities and their environments. This lead to the erosion of cultural identity, loss of traditional livelihoods, and challenges in preserving cultural heritage.

Social cost of carbon

About

- The social cost of carbon (SCC) is an economic concept used to estimate the economic damages associated with each additional metric ton of carbon dioxide emissions.
- It represents the monetary value of the long-term impact of carbon dioxide emissions in terms of environmental damage, public health costs, and other societal costs resulting from climate change.
- This value is then utilized to assess the advantages of reducing global warming against the costs of cutting emissions.
- The social cost of carbon (SCC) is an attempt to quantify the economic value of the benefits and drawbacks associated with emitting an additional metric ton of carbon dioxide.
- According to the Organization for Economic Cooperation and Development (OECD), the SCC is calculated as the present value of the net climate change impacts over a period of 100 years or more resulting from the emission of one extra ton of carbon into the atmosphere today.

Objective

- The purpose of using the SCC is to address the market failure that occurs when the costs of emitting carbon dioxide are borne by society as a whole, while the benefits are accrued by those who burn fossil fuels.

Significance

- By determining the social cost of these carbon dioxide emissions, measures such as a carbon tax is implemented to correct this market failure.
- By comparing the costs of reducing emissions with the estimated damages avoided, policymakers assess the benefits and costs of various mitigation strategies.
- The SCC has been used by governments and organizations to inform policy decisions, such as setting emissions targets, designing carbon pricing mechanisms, and evaluating the benefits of climate change mitigation measures.